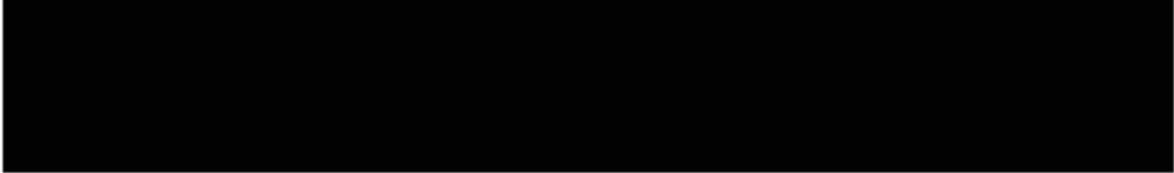


**From:** [Yingling, Gary L.](#)  
**To:** [McMahon, Carrie](#)  
**Cc:** [Vaughn, Jessica L.](#)  
**Subject:** FW: Impossible Foods Letter Regarding Color Additive Regulations  
**Date:** Wednesday, October 18, 2017 4:04:38 PM  
**Attachments:** [\(93593290\) \(8\) FDA Response Letter - Soy Leghemoglobin and Color Additive Regulations \(2\).DOCX](#)  
[Attachment 1 Impossible Foods Patent US9700067.pdf](#)

---

Dear Dr. McMahon: Attached is a letter to the Agency responding to the color additive question.  
Please accept my apology because it was suppose to have been sent last week. gary

**Gary L. Yingling**  
**Morgan, Lewis & Bockius LLP**  


---

**From:** Vaughn, Jessica L.  
**Sent:** Wednesday, October 18, 2017 3:32 PM  
**To:** Yingling, Gary L.  
**Subject:** Impossible Foods Letter Regarding Color Additive Regulations

Hi Gary,  
Letter and Patent attached.  
  
-Jessica

**Jessica L. Vaughn, Ph.D.**  
Regulatory Scientist  
**Morgan, Lewis & Bockius LLP**  


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# Morgan Lewis

**Gary L. Yingling**

Senior Counsel

October 18, 2017

Carrie McMahon, Ph.D.  
Consumer Safety Officer  
Office of Food Additive Safety  
U.S. Food and Drug Administration  
5001 Campus Drive  
College Park, MD 20740

Re: Soy Leghemoglobin Protein as a Flavor Catalyst

Dear Dr. McMahon:

This letter responds to the Food and Drug Administration's ("FDA" or "Agency") color additive inquiry in a September 5, 2017 email to our client, Impossible Foods Inc. ("Impossible Foods"), concerning the use of soy leghemoglobin protein derived from *Pichia pastoris* ("soy leghemoglobin") in the Impossible Burger.

Soy leghemoglobin was originally sourced from soybean root nodules, and is produced by Impossible Foods via fermentation using *Pichia pastoris* that has been genetically modified to express soy leghemoglobin. Impossible Foods uses soy leghemoglobin as an ingredient of the Impossible Burger for the sole purpose of driving the chemistry that creates the flavor and aroma of meat. Impossible spent years researching how raw meat transforms from its bland, metallic taste into the complex profile of flavors and aromas that make cooked meat uniquely appealing and flavorful. Impossible Foods discovered that, when exposed to heat (i.e., cooking) a heme protein present in meat (myoglobin) catalyzes the various vitamins, minerals, amino acids and simple sugars found naturally in the surrounding meat tissues, thereby generating meat flavors and aromas. To create a plant-based analog to meat, Impossible Foods researched various plant-based heme proteins, and chose soy leghemoglobin as it actually performs the same function – as a flavor catalyst - as myoglobin in meat, and in some ways, performs even better than myoglobin (e.g., shelf life). The flavor chemistry made possible by soy leghemoglobin is what makes the plant-based Impossible Burger unique.

Because the flavor chemistry made possible by using soy leghemoglobin is so important and novel, Impossible Foods sought a patent covering the use of soy leghemoglobin as a

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flavor catalyst in plant-based foods. The Patent and Trademark Office recognized the inventiveness of Impossible Foods's use of soy leghemoglobin to drive flavor chemistry, and on July 11, 2017, granted to Impossible Foods U.S. Patent No. 9,700,067 B2, "Methods and Compositions for Affecting the Flavor and Aroma Profiles of Consumables" (Attachment 1). The patent discusses, at length, the use of the soy leghemoglobin to "modulate the flavor and/or aroma profile of other foods" and provides over 14 examples of various flavor profiles enabled by soy leghemoglobin (see pp. 21-34 of Attachment 1). Further supporting soy leghemoglobin's use solely for flavor, like many flavors, its use level in food is limited because it will impart an increasingly strong and disagreeable taste if used at levels above 0.8%.

The Agency noted that in posted material Impossible had referenced the red color of soy leghemoglobin, and the Agency asked whether the soy leghemoglobin was a color additive. Impossible does not believe the leghemoglobin is a color additive and consistent with this point, has removed all references in its materials to this inaccurate characterization of use of soy leghemoglobin. Impossible Foods provides further support of its conclusion through the following reasons.

The definition of the term "color additive" found in 21 U.S.C. § 321(t)(B) requires a material to be "added or applied to a food." Soy leghemoglobin is neither added nor applied to a food; rather, soy leghemoglobin is the most important functional ingredient of the food itself. The burger's other main ingredients are wheat protein, deflavored coconut oil and potato protein; the burger would taste entirely bland in the absence of the meaty flavor and aroma properties made possible by the soy leghemoglobin food ingredient. Without soy leghemoglobin, the Impossible Burger would be no different from any of the legion of "veggie burgers" on the market that may taste good, but would never be mistaken for meat. The flavor function of soy leghemoglobin is so important and integral that, as mentioned above, Impossible has secured its exclusive use by obtaining US Patent No. 9,700,067 B2.

Further, in the color additive regulations, 21 C.F.R. § 70.3(f), a food ingredient such as cherries, green or red peppers, chocolate and orange juice, which contribute their own natural color when mixed with other foods, are not regarded as color additives. Likewise, soy leghemoglobin is a food ingredient used for the sole purpose of flavor that will nonetheless impart its natural color to the food. Soy leghemoglobin drives the flavor chemistry of the burger, and is a critically necessary ingredient for that reason alone.

The food color additive ingredients listed in 21 C.F.R. § 73.1 to § 73.615, have a color property and limited, if any, impact other than color. That is not the case with soy leghemoglobin. Soy leghemoglobin has a critical impact by driving the chemistry that produces the distinctive flavor and aroma of meat. Impossible Foods uses soy leghemoglobin as a flavor catalyst. The heme molecule catalyzes flavor and has a natural color and it is not possible to extract the color from soy leghemoglobin without destroying the flavor properties.

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Thus, as stated at the outset, soy leghemoglobin is used for its ability to impart the flavor and aroma of meat in a plant-based product. It is not a color additive, pursuant to 21 C.F.R. § 70.3(f).

We hope we have addressed your questions.

Sincerely,

A handwritten signature in black ink, appearing to read "Gary L. Yingling". The signature is written in a cursive style with some variations in letter height and thickness.

Gary L. Yingling

GLY



US009700067B2

(12) **United States Patent**  
**Fraser et al.**(10) **Patent No.:** US 9,700,067 B2  
(45) **Date of Patent:** Jul. 11, 2017(54) **METHODS AND COMPOSITIONS FOR AFFECTING THE FLAVOR AND AROMA PROFILE OF CONSUMABLES**(71) Applicant: **Impossible Foods Inc.**, Redwood City, CA (US)(72) Inventors: **Rachel Fraser**, San Francisco, CA (US); **Patrick O'Reilly Brown**, Stanford, CA (US); **Jessica Karr**, San Francisco, CA (US); **Celeste Holz-Schietinger**, East Palo Alto, CA (US); **Elysia Cohn**, Mountain View, CA (US)(73) Assignee: **Impossible Foods Inc.**, Redwood City, CA (US)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: 14/797,006

(22) Filed: Jul. 10, 2015

(65) **Prior Publication Data**

US 2015/0351435 A1 Dec. 10, 2015

**Related U.S. Application Data**

(63) Continuation of application No. PCT/US2014/011347, filed on Jan. 13, 2014, which (Continued)

(51) **Int. Cl.**  
A23J 1/14 (2006.01)  
A23J 3/14 (2006.01)

(Continued)

(52) **U.S. CL.**  
CPC . A23J 3/14 (2013.01); A23J 1/12 (2013.01); A23J 1/14 (2013.01); A23J 3/227 (2013.01); (Continued)(58) **Field of Classification Search**  
CPC ..... A23L 1/221; A23L 1/231; A23L 1/31427  
See application file for complete search history.(56) **References Cited**

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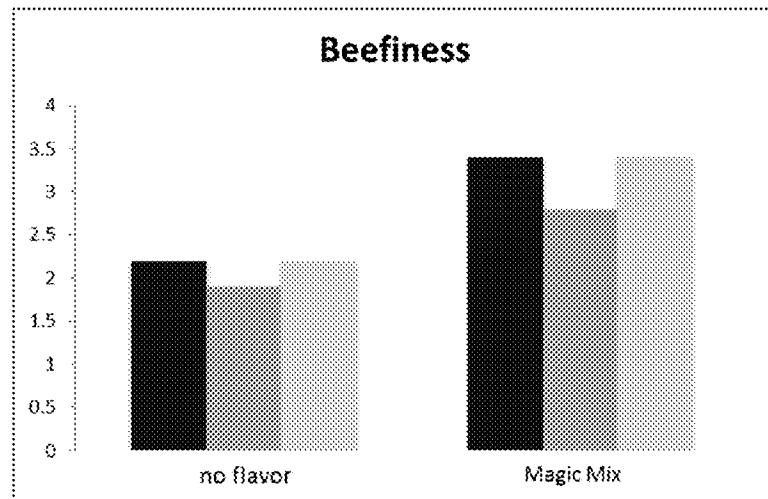
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Primary Examiner — Elizabeth Gwartney

(74) Attorney, Agent, or Firm — Fish &amp; Richardson P.C.

(57) **ABSTRACT**

This document relates to food products containing highly conjugated heterocyclic rings complexed to an iron ion and one or more flavor precursors, and using such food products to modulate the flavor and/or aroma profile of other foods. The food products described herein can be prepared in various ways and can be formulated to be free of animal products.

**23 Claims, 5 Drawing Sheets**

**Related U.S. Application Data**

is a continuation of application No. 13/941,211, filed on Jul. 12, 2013.

(60) Provisional application No. 61/908,634, filed on Nov. 25, 2013, provisional application No. 61/751,816, filed on Jan. 11, 2013.

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**FIG. 1**SEQ ID NO:1 *Vigna radiata*MTTTLERGFTEEQEALVVKSWNMKNSGELGLKFFLKIFEIAPSAAQKLFSFLRDSTVPLEQNPK  
LKHAVSVFVMTCDSAVQLRKAGKVTVRESNLKKLGATHFRTGVANEHFEVTKFALLETIKEAVP  
EMWSPAMKNAWGEAYDQLVDAIKYEMKPPSSSEQ ID NO:2 *Methylacidiphilum infernorum*MIDQKEKELIKESWKRIEPNKNEIGLLFYANLFKEEPVSVLFQNPISQSRSRKLMOVLGILVQGI  
DNLEGLIPTLQDLGRRHKQYGVVDSHYPLVGDCLLKSIQEYLQGFTEEAKAAWTKVYGINAQVM  
TAESEQ ID NO:3 *Aquifex aeolicus*MLSEETIRVIKSTVPLLKEHGTEITARMYELLFSKYPKTKEFLFAGASEEQPKKLANAIIAYATYI  
DRLEELDNAISTIARSHVRRNVKPEHYPLVKECLLQAIEEVLPNGEEVLKAWEAAYDFLAKTLIT  
LEKKLYSQPSEQ ID NO:4 *Glycine max*MGAFTEKQEALVSSSFEAFKANIPOYSVVFYTSILEKAPAAKDLFSFLSNGVDPNSPKLTGHAEK  
LFGLVRDSAGQLKANGTVVADAALGSIHQAQKAITDPQFVVVKEARLKIKEAVGDKWSDELSSAW  
EVAYDELAAAIIKKAFSEQ ID NO:5 *Hordeum vulgare*MSAAEGAVVFSEEKEALVLKSWAIMKKDSANLGLRFFLKIFEIAPSARQMFPFLRDSDVPLETNP  
KLKTHAVSVFVMTCEAAQLRKAGKITVRETLKRLGGTHLKYGVADGHFEVTRFALLETIKEAL  
PADMWGPEMRNAWGEAYDQLVAAIKQEMKPAESEQ ID NO:6 *Magnaporthe oryzae*MDGAVRLDWWTGLDLTGHEIHDGVPPIASRVQVMVSFPLFKDQHIIMSSKESPSRKSSTIGQSTRNG  
SCQADTQKGQLPPVGEGPKPKPVKENPMKKLKEMSQRPLPTQHGDGTYPTEKKLTGIGEDLKHIRGY  
DVKTLLAMVSKSLKGEKLKDDEKTMERMVQLVARLPTESKKRAELTDSLINELWESLDHPPLNY  
LGPEHSYRTPDGSYNHPFPNQLGAAGSRYARSVIPTVTPPGALPDGPLIFDSIMGRTPNSYRKHP  
NNVSSILWYWATIIIHDIFWTDPRDINTNKSSSYLDLAPLYGNSQEMQDSIRTFKDGRMKPDCYA  
DKRLAGMPPGVSVLLIMFNRFHNHVAENLALINEGGFRNFKPSDLLEGAREAAWKKYDNDLFQVA  
RLVTSGLYINITLVDYVRNIVNLNRVDTTWLDPRDAGAHVGTADGAERTGNAVSAEFNLCYR  
WHSCCISEKDSKFVEAQFQNIFGKPASEVRPDEMWKFAKMEQNTPADPGQRTFGGFKRGPDGKFD  
DDDLVRCISEAVEDVAGAFGARNVPQAMKVETMGIIQGRKWNVAGLNEFRKHFHLKPYSTFEDI  
NSDPGVAEALLRLYDHDPDNVELYPLGLVAEEDKQPMVPGVGIAPTYTISRVVLSDAVCLVRGDRFY  
TTDFTPRNLTNWGYKEVDYDL SVNHGCVFYKLFIRAFPNFKQNSVYAHYPMVVPSENKRILEAL  
GRADLFDFEAPKYIIPPRVNITSYGGAEYILETQEKYKVTWHEGLGLMGEGLKFM LSGDDPLHA  
QQRKCMAAQLYKDGWTEAVKAFYAGMMEELLVSKSYFLGNKHRHVDIIRDVGNMVHVHFASQVF  
GLPLKTAKNPTGVTEQEMYGILAIFTTIFDLDPSKSFPLRTKREVCKQLAKLVEANVKLIN  
KIPWSRGMFVGKPAKDEPLSIYGKTMIKGLKAHGLSDYDIASHVVPSTSGAMVPNQAQVFAQAVD  
YYLSPAGMHYIPEIHMVALQPSTPETDALLGYAMEGIRLAGTFGSYREA VDDVVKEDNGRQVP  
VKAGDRVFSFVDAARDPKHFPDPEVNP RRPAKKYIH YGVGPHACLGRDASQIAITEMFRCLFR  
RRNVRVPGPQGELKKVPRPGFYVYMREDWGGLFPFPVTMRVMWDDESEQ ID NO:7 *Fusarium oxysporum*MKGSATLAFALVQFSAASQLWPSKWDEVEDLLYMQGGFNKRGFADALRTCEF GS NVP GTQNTAE  
WLRTAFHDAITHDAKAGTGGLDASIYWESSR PENPGKAFNNTFGFSGFHNPRATASDL TALGT  
LAVGACNGPRIPFRAGR IDAYKAGPAGVPEPSTNLKDTFAFTKAGFTKEEMTAMVACGHAIGGV

## FIG. 1-CONT.

HSVDPPEIVGIKADPNNDTNVPFQKDVSFHNGIVTEYLAGTSKNPLVASKNATFHSDKRIFDND  
KATMKKLSTKAGFNSMCADILTRMIDTPKSVQLTPVLEAYDVRPYITELSLNNKNKIHTGSVR  
VRITNNIRDNNDLAINLIYVGRDGKVTPTQQVTFGGGTSGAGEVFANFEFDTTMDAKNGITK  
FFIQEVKPSTKATVTHDNQKTGGYKVDDTVLYLQQSCAVIEKLPNAFLVVTAMVRDARAKDAL  
LRAVAKKPKVKGSIIVPRFQTAITNFKATGKKSSGYTFQAKTMEEQSTYFDIVLGSPASGVQFL  
TSQAMPSQCS

SEQ ID NO:8 *Fusarium graminearum*

MASATRQFARAATRATRNGFAIAPRQVIROQQGRYYSSPAQKSSSAWIWLTGA  
AVAGGAGYYFY  
GNSASSATAKVFNPSKEDYQKVYNEIAARLEEKDDYDDGSYGPVLVRLAWHASGTYD  
KETGTGGS  
NGATMRFAPESDHGANAGLAAARDFLQPVKEKF  
PWITYSDLWILAGVCAI  
QEMLGP  
AIPYRPGRS  
DRDVGCTPDGRLPDASKRQDHLRGIFGRMGFNDQEIVALSGAHALGRCH  
TDRSGYSGPWTFSPT  
VLTNDYFRLVEEKWQWKWNGPAQYEDKSTKS  
LMM  
LFS  
DIALIEDKKFK  
PWVEKYAKDND  
AFFK  
DFSNVVLRLFELGV  
PFAQGTENQRWTFK  
PHTHQE

SEQ ID NO: 9 *Chlamydomonas eugametos*

MSLFAKLGGREAVEAAVDKFYNKIVADPTVSTYFSNTDMKVQRSKQFAFLAYALGGASEWKGKDM  
RTAHKDLVPHLSDVHFQAVARHLS  
DTLTELGV  
PPEDITDAMAVVASTRTEV  
LNMPQQ

SEQ ID NO:10 *Tetrahymena pyriformis*

MNKPQT  
IYEKLG  
GENAMKA  
AVPLFYK  
VLA  
DERVK  
HFFK  
NTDMDH  
QTK  
QQTDF  
LTML  
GGPN  
HYK  
GKNM  
TEAHKG  
MNLQ  
NLHF  
DAII  
ENLA  
ATLK  
ELGV  
TD  
AVINE  
AAK  
VIEH  
TRK  
DMLGK

SEQ ID NO:11 *Paramecium caudatum*

MSLF  
EQLGG  
QA  
VQAV  
TAQ  
FYAN  
IQAD  
ATV  
ATFF  
NGID  
MPN  
QTN  
KTA  
AFL  
CAL  
GGP  
NA  
WT  
GRNL  
KEV  
HAN  
MGV  
SNA  
QFT  
TIV  
IGH  
LRS  
ALT  
GAG  
VAA  
LVE  
QTV  
AVA  
ETV  
RGD  
VVTV

SEQ ID NO:12 *Aspergillus niger*

MPLTPEQIKII  
KATV  
PVLQ  
EYGT  
KITTA  
FYM  
NMST  
VHP  
ELNAV  
FNT  
ANQ  
VKGH  
QAR  
ALA  
GAL  
FAY  
ASH  
DDL  
GAL  
GPA  
VEL  
ICN  
KHA  
SLY  
IQA  
DEY  
KIV  
GKY  
LLE  
AMK  
EV  
LGD  
ACT  
DD  
I  
L  
D  
A  
W  
G  
A  
A  
Y  
W  
A  
L  
D  
I  
M  
I  
N  
R  
E  
A  
A  
L  
Y  
K  
Q  
S  
Q  
G

SEQ ID NO:13 *Zea mays*

MALAEADDGAVV  
FGEE  
QEAL  
VLK  
SWAV  
MKDA  
ANL  
GLR  
FFL  
KV  
FEI  
APS  
AEQM  
FSFL  
RDSD  
VP  
LE  
KNP  
KLK  
THAM  
SVF  
VMT  
CEAAA  
QLR  
KAG  
KV  
T  
RE  
TLK  
RLG  
ATH  
FKY  
GVG  
DAH  
FEV  
TRF  
ALL  
ETI  
KEA  
PV  
DMW  
SPAM  
KSA  
WEA  
Y  
SQL  
VAA  
I  
K  
REM  
K  
P  
D  
A

SEQ ID NO:14 *Oryza sativa subsp. japonica*

MALVEGN  
NGV  
SGG  
AVSF  
SEE  
QEAL  
VLK  
SWAIM  
KKDS  
SANIG  
LRF  
FLK  
I  
FEV  
APS  
ASQM  
FSFL  
RN  
SD  
V  
PLE  
KNP  
KLK  
THAM  
SVF  
VMT  
CEAAA  
QLR  
KAG  
KV  
T  
RE  
TLK  
RLG  
ATH  
FKY  
GVG  
DAH  
FEV  
TRF  
ALL  
ETI  
KEA  
PV  
DMW  
SPAM  
KSA  
WEA  
Y  
SQL  
VAA  
I  
K  
REM  
K  
P  
D  
A

SEQ ID NO:15 *Arabidopsis thaliana*

MESEGK  
IVF  
TEE  
QEAL  
VV  
KWS  
VM  
KK  
NSA  
EL  
GL  
KLF  
I  
FEI  
AP  
TT  
KK  
MF  
SFL  
RD  
SP  
I  
PA  
EQ  
NP  
K  
LK  
PHAM  
SVF  
VM  
CC  
ESA  
V  
QLR  
KT  
G  
KV  
T  
RE  
TL  
K  
RL  
G  
ASH  
SKY  
GV  
V  
DEH  
FEV  
AKY  
ALLE  
TI  
KEA  
PV  
EM  
WSPE  
M  
KVA  
WGQ  
AYD  
HLV  
AA  
I  
KA  
EM  
NL  
SN

## FIG. 1-CONT.

SEQ ID NO:16 *Pisum sativum*

MGFTDKQEALVNSSWESFKQNLSGNSILFYTIILEKAPAAKGLFSFLKD TAGVEDSPKLQAHAEQ  
VFGLVRD SAAQLRTKG EVV LGNATLGAIHVQRGV DPHF VVV KE ALL QTIKKAS GNNWSEELNTA  
WEVAYDGLATAIKKAMT

SEQ ID NO:17 *Vigna unguiculata*

MVA FSDKQE ALVN GAYE AFKANI PKY SVV FYTTILEKAPAAKNL FSFLANGV DATNP KLTG HAEK  
LF GLVRD SAAQ L RASGGV VADA ALGA VHSQ KAVN DAQF VVV KE ALV KTLKE AVG DKWS DEL GTAV  
ELAYDE LAAI KKAY

SEQ ID NO:18 *Bos taurus*

MGLSDGEWQLVLNAWGKV EADVAGHGQEV LIRLFTGH PETLEKFDKF KHLKTEAEMKASEDLKKH  
GNTVLT ALGGILKKKGHEAEV KH LAESHANKH KIPVKYLEFISDAII HVLHAKHPSDFGADAQA  
AMSKALELFRNDMAAQYKVLGFHG

SEQ ID NO:19 *Sus scrofa*

MGLSDGEWQLVLNVWGKV EADVAGHGQEV LIRLFTGH PETLEKFDKF KHLKSEDEMKA SEDLKKH  
GNTVLT ALGGILKKKGHEAE LTPLAQSHATKH KIPVKYLEFIS EAI IQVLQSKH  
PGDFGADAQGAMS KALELFRNDMAAKYKELGFQG

SEQ ID NO:20 *Equus caballus*

MGLSDGEWQVLNVWGKV EADIAGHGQEV LIRLFTGH PETLEKFDKF KHLKTEAEMKASEDLKKH  
GTVVLT ALGGILKKKGHEAE ELKPLAQSHATKH KIPVKYLEFISDAII HVLHSKH  
PGDFGADAQGAMTKALELFRNDIAAKYKELGFQG

SEQ ID NO:21 *Nicotiana benthamiana*

MSSFTEEQ EALVVKS WDSM KKNAGEWGLKLFLKIFEIAPS A KLF SFLK DS NV PLEQ NAKLKPHS  
KSVF VMT CEA AVQLRKAG KV VV RDST LKKLGATHFKYGV ADEHFEV TKF ALLET I KEAV PEMWSV  
DMKNAWGEAFDQLVNAIKTEMK

SEQ ID NO:22 *Bacillus subtilis*

MGQSFNAP YEAIGE ELLSQLVDTFYERVASHPLLKPIFPSDLTETARKQKQFLTQYLGGPPLYTE  
EHGPMLRARHLPFPITNERADAWLSCMKDAMDHV GLEGEIREFLFGRLELTARHMVNQTEAEDR  
SS

SEQ ID NO:23 *Corynebacterium glutamicum*

MTTSENFYDSVGGEETFSLIVH RFYEQVPN DILGP MYPP DD FEGAEQRLKMF LSQYWG GPKDYQ  
EQR GHPR LRM R HVN YPIGV TAAERWLQ LMSN ALDGV DL TAEQ REAI WEHM VRAADM LINS NPD PH  
A

SEQ ID NO:24 *Synechocystis* PCC6803

MSTLYEKLGGTTAVDLAVDKFYERVLQDDRIKHFFADVDMAKQRAHQKAFLTYAFGGTDKYDGRY  
MREAHKELVENHGLNGEHF DAVAEDLLATL KEMGV PEDLIAEVA AVAGAPA HKRD VL NQ

SEQ ID NO:25 *Synechococcus* sp. PCC 7335

MDVALLEKSF EQIS PRAIEFS ASFYQNL FH HPELKPLFAETS QTIQ EKKLIF SLAA IENLRNP  
DILQPALKSLGARHAEVGTIKSHYPLVGQALIETFAEYLAADWTEQLATAWVEAYDVIASTMIEG  
ADNP AAYLEPELTFYEWLDLYGEESP KVRN AIA TLTHFHYGEDPQDV QRSRG

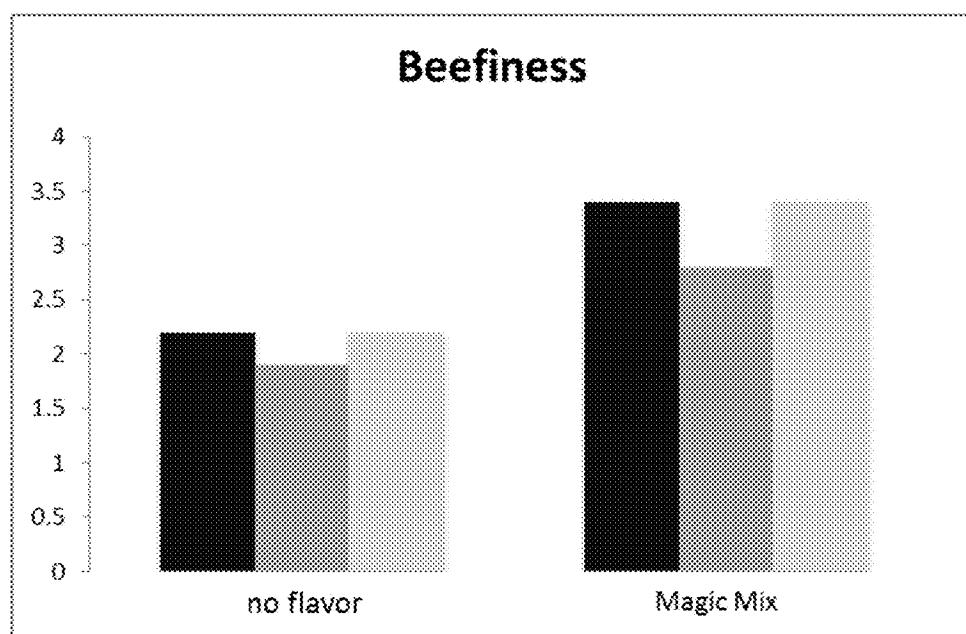
**FIG. 1-CONT.**

SEQ ID NO:26 *Nostoc commune*

MSTLYDNIGGQPAIEQVVDELHKRIATDSLLAPVFAGTDMVKQRNHLVAFQIFEGPKQYGGRP  
MDKTHAGLNLQQPHFDAIAKHLGERMAVRGSAENTKAALDRVTNMKGAILNK

SEQ ID NO:27 *Bacillus megaterium*

MREKIHSPYELLGGEHTISKLVDAFYTRVGQHPELAPIFPDNLTEARKQKQFLTQYLGGPSLYT  
EEHGHPMRLRARHLPFEITPSRAKAWLTCMHEAMDEINLEGPERDELYHRLILTAQHMINSEQTD  
EKGFSH

**FIG. 2**

1

**METHODS AND COMPOSITIONS FOR  
AFFECTING THE FLAVOR AND AROMA  
PROFILE OF CONSUMABLES**

**CROSS-REFERENCE TO RELATED  
APPLICATIONS**

This application is a continuation and claims priority to PCT/US2014/011347 which claims priority to U.S. application Ser. No. 13/941,211, filed Jul. 12, 2013, U.S. Application Ser. No. 61/908,634, filed Nov. 25, 2013, and to U.S. Application Ser. No. 61/751,816, filed Jan. 11, 2013, and is related to the following patent applications: Application Serial No. PCT/US12/46560; Application Serial No PCT/US12/46552; Application Ser. No. 61,876,676, filed Sep. 11, 2013; and Application Ser. No. 61/751,818, filed Jan. 11, 2013, all of which are incorporated herein by reference.

**TECHNICAL FIELD**

This invention relates to food products and more particularly, to food products that include a highly conjugated heterocyclic ring complexed to iron such as a heme-cofactor and one or more flavor precursor molecules.

**BACKGROUND**

Food is any substance that is either eaten or drunk by any animal, including humans, for nutrition or pleasure. It is usually of plant or animal origin, and can contain essential nutrients, such as carbohydrates, fats, proteins, vitamins, or minerals. The substance is ingested by an organism and assimilated by the organism's cells in an effort to produce energy, maintain life, or stimulate growth.

Food typically has its origin in a photosynthetic organism, such as a plant. Some food is obtained directly from plants, but even animals that are used as food sources are raised by feeding them food which is typically derived from plants.

In most cases, the plant or animal food source is fractionated into a variety of different portions, depending upon the purpose of the food. Often, certain portions of the plant, such as the seeds or fruits, are more highly prized by humans than others and these are selected for human consumption, while other less desirable portions, such as the stalks of grasses, are typically used for feeding animals.

Current plant-based meat substitutes have largely failed to cause a shift to a vegetarian diet. Meat substitute compositions are typically extruded soy/grain mixtures which largely fail to replicate the experience of cooking and eating meat. Common limitations of plant-based meat substitute products are a texture and mouth-feel that are more homogenous than that of equivalent meat products. Furthermore, as these products must largely be sold pre-cooked, with artificial flavors and aromas pre-incorporated, they fail to replicate the aromas, flavors, and other key features, such as texture and mouth-feel, associated with cooking or cooked meat. As a result, these products appeal largely to a limited consumer base that is already committed to vegetarianism/veganism, but have failed to appeal to the larger consumer segment accustomed to eating meat. It would be useful to have improved plant-based meat substitutes which better replicate the aromas and flavors of meat, particularly during and/or after cooking.

**SUMMARY**

Provided herein are methods and compositions for modulating the flavor and/or aroma profile of consumable food

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products, including animal- or non-animal (e.g., plant) based food products, or mixtures of animal- and non-animal-based food products. In some embodiments, the methods and compositions are useful for modulating the flavor and/or aroma profile of a consumable food product during and/or after the cooking process. In some embodiments, the methods and compositions are used to generate one or more chemical compounds that modulate the flavor and/or aroma profile of the consumable food product during and/or after the cooking process.

As provided herein, and without being bound by theory, certain characteristic meaty flavors and/or aromas (e.g., beefy, bacony, umami, savory, bloody, brothy, gravy, metallic, bouillon-like; see Tables 2, 7, and 11), including one or more specific chemical compounds associated with the same (see Tables 3, 8, 9, 12, 14, 16, or 17), are believed to be produced during the cooking process of a consumable food product by chemical reaction of one or more flavor precursor molecules or compositions catalyzed by the presence of a highly conjugated heterocyclic ring complexed to an iron ion (e.g., a heme moiety; or a porphyrin; a porphyrinogen; a corrin; a corrinoid; a chlorin; a bacteriochlorophyll; a coporphin; a chlorophyllin; a bacteriochlorin; or an isobacteriochlorin moiety complexed to an iron ion). Such highly conjugated heterocyclic moieties include heterocyclic aromatic rings composed of one or more (2, 3, or 4 more) pyrrole, pyrrole-like, and/or pyrrolidine subunits. The highly conjugated heterocyclic ring complexed to an iron ion is referred to herein as an iron complex. In some embodiments, the heme moiety can be a heme cofactor such as a heme moiety bound to a protein; a heme moiety bound to a non-proteinaceous polymer; a heme moiety bound to a solid support; or a heme moiety encapsulated in a liposome. In some embodiments, the flavors and/or aromas are not generated in the absence of the iron complex (e.g., in the absence of a ferrous chlorin) or are not generated in the absence of a heme-cofactor (e.g., in the absence of a heme-containing protein). Accordingly, as described herein, the iron complexes such as isolated chlorin-iron complexes or heme-cofactors (e.g., heme-containing proteins) can be used to generate meaty flavors and/or aromas in a variety of food products, such as during the cooking process.

Combining one or more iron complexes such as a heme-cofactor (e.g., a heme-containing protein, including, for example a plant-derived heme protein such as a plant leghemoglobin (legH)), with one or more flavor precursor molecules or compositions (see, e.g., Table 1 or Table 13) can generate or provide a range of savory and meaty aromas and tastes (see, e.g., Tables 2, 7, and/or 11) in a cooked consumable food product. Flavor precursor molecules or compositions can be added to the uncooked food product in purified form and/or can be derived from ingredients in the uncooked consumable food product that contain and/or are enriched with one or more of the particular flavor precursors or compositions, including, for example, yeast extract, vegetable oil, corn oil, soybean oil, palm fruit oil, palm kernel oil, safflower oil, flaxseed oil, rice bran oil, cottonseed oil, olive oil, canola oil, sunflower oil, coconut oil, mango oil, or an algal oil. The resultant flavor and/or aroma profile can be modulated by the type and concentration of the flavor precursors, the pH of the reaction, the length of cooking, the type and amount of iron complex (e.g., a heme cofactor such as a heme-containing protein), the temperature of the reaction, and the amount of water activity in the product, among other factors.

One or more flavor precursor molecules or compositions can be added along with a iron complex (e.g., ferrous

chlorophyllin or a heme cofactor such as a heme-containing protein), to an uncooked food product, before and/or during the cooking process, to give the cooked consumable food product a particular meaty taste and smell, for example, the taste and smell of beef, bacon, pork, lamb, or chicken. Consumable food products can be animal or non-animal based (e.g., plant) food products, or combinations of an animal and non-animal based food product. For example, a plant based veggie burger or an animal-based burger, such as a chicken burger, can be modified with the compositions and methods of the present disclosure to result in a burger having a cooked flavor and/or aroma profile that is more meat like, e.g., beef-like, lamb-like, pork-like, turkey-like, duck-like, deer-like, yak-like, bison-like or other desirable meat flavor.

Food products for use in the present disclosure include those that have an iron-complex (e.g., a heme cofactor such as a heme-containing protein), and one or more flavor precursor molecules included therein. The iron-complex such as a heme cofactor (e.g., a heme-containing protein) and the one or more flavor precursor molecules can be homogenously or heterogeneously included in the food products. A heme protein can be isolated and purified prior to inclusion in the food product. Non-limiting examples of consumable food products which can include an iron complex such as a heme-cofactor (e.g., a heme-containing protein) and one or more flavor precursor molecules include animal-based or non-animal (e.g., plant-based), or combinations of animal-based and non-animal-based, food products in the form of hot dogs, burgers, ground meat, sausages, steaks, filets, roasts, breasts, thighs, wings, meatballs, meatloaf, bacon, strips, nuggets, cutlets, or cubes.

Consumable food products for use in the present disclosure can be flavor additive compositions, e.g., for addition to another consumable food product before, during, or after its cooking process. A flavor additive composition can include an iron complex such as a heme-cofactor (e.g., a heme-containing protein), and one or more flavor precursors.

A flavor additive composition can include a heme protein, e.g., an isolated and purified heme protein; such a flavor additive composition can be used to modulate the flavor and/or aroma profile of a consumable food product that comprises one or more flavor precursor molecules or compositions. A flavor additive composition can include one or more flavor precursor molecules or compositions; such a flavor additive composition can be used to modulate the flavor and/or aroma profile of a consumable food product that comprises the heme protein, e.g., an isolated and purified heme protein.

A flavor additive composition can be in the form, of but not limited to, soup or stew bases, bouillon, e.g., powder or cubes, flavor packets, or seasoning packets or shakers. Such flavor additive compositions can be used to modulate the flavor and/or aroma profile for a variety of consumable food products, and can be added to a consumable food product before, during, or after cooking of the consumable food product.

In some embodiments, a flavor additive composition such as one including an iron complex (e.g., ferrous chlorin or a heme protein) and one or more flavor precursors can be reacted (e.g., in vitro) with heating to generate a particular flavor and/or aroma profile of interest and the resultant product mixture can be added to the consumable food product of interest, which can then be eaten as-is or can be additionally modified, e.g., by additional cooking. In some embodiments, the iron complex can be removed from the resultant product mixture before adding the product mixture to the consumable food product of interest. For example, the

iron complex can be removed from the product mixture using chromatographic techniques such as column chromatography, e.g., a column containing heme or iron-chlorin.

In some embodiments, the iron complex such as a heme-cofactor, e.g., a heme-protein, and the one or more flavor precursor flavor additive compositions can be soy-free, wheat-free, yeast-free, MSG-free, and free of protein hydrolysis products, and can taste meaty, highly savory, and without off odors or flavors.

10 In one aspect, this document features a food product that includes an iron complex such as a heme moiety, or a porphyrin, a porphyrinogen, a corrin, a corrinoid, a chlorin, a bacteriochlorophyll, a corphin, a chlorophyllin, a bacteriochlorin, or an isobacteriochlorin moiety complexed to an iron ion and one or more flavor precursor molecules selected from the group consisting of glucose, fructose, ribose, arabinose, glucose-6-phosphate, fructose 6-phosphate, fructose 1,6-diphosphate, inositol, maltose, sucrose, maltodextrin, glycogen, nucleotide-bound sugars, molasses, a phospholipid, a lecithin, inosine, inosine monophosphate (IMP), guanosine monophosphate (GMP), pyrazine, adenosine monophosphate (AMP), lactic acid, succinic acid, glycolic acid, thiamine, creatine, pyrophosphate, vegetable oil, algal oil, corn oil, soybean oil, palm fruit oil, palm kernel oil, safflower oil, flaxseed oil, rice bran oil, cottonseed oil, sunflower oil, canola oil, olive oil, a free fatty acid, cysteine, methionine, isoleucine, leucine, lysine, phenylalanine, threonine, tryptophan, valine, arginine, histidine, alanine, asparagine, aspartate, glutamate, glutamine, glycine, proline, serine, tyrosine, glutathione, an amino acid derivative, a protein hydrolysate, a malt extract, a yeast extract, and a peptone. The heme moiety can be a heme-containing protein, a heme moiety bound to a non-peptidic polymer; or a heme moiety bound to a solid support. The heme-containing protein can be a plant, mammalian, a yeast or filamentous fungi, or bacterial heme-containing protein. The food product can include two to one hundred, two to fifty flavor precursors, two to forty flavor precursors, two to thirty-five flavor precursors, two to ten flavor precursors, or two to six flavor precursors. In some embodiments, the one or more flavor precursor molecules are selected from the group consisting of glucose, ribose, cysteine, a cysteine derivative, thiamine, alanine, methionine, lysine, a lysine derivative, glutamic acid, a glutamic acid derivative, IMP, GMP, lactic acid, maltodextrin, creatine, alanine, arginine, asparagine, aspartate, glutamic acid, glutamine, glycine, histidine, isoleucine, leucine, methionine, phenylalanine, proline, threonine, tryptophan, tyrosine, valine, linoleic acid, and mixtures thereof. The heme-containing protein can be a non-symbiotic hemoglobin or a leghemoglobin (e.g., a plant leghemoglobin such as one from soybean, alfalfa, lupin, pea, cow pea, or lupin). The heme-containing protein can include an amino acid sequence having at least 80% sequence identity to a polypeptide set forth in SEQ ID NOs:1-26. The heme-containing protein can be isolated and purified. The food product further can include a food-grade oil, a seasoning agent, a flavoring agent, a protein, a protein concentrate, an emulsifier, a gelling agent, or a fiber. The food product can be a meat substitute, a soup base, stew base, snack food, bouillon powder, bouillon cube, a flavor packet, or a frozen food product. Any of the food products can be free of animal products. The food product can be sealed within a packet or shaker.

This document also features a method for producing a flavor compound. The method can include combining an iron complex (e.g., a heme moiety, a porphyrin, a porphyrinogen, a corrin, a corrinoid, a chlorin, a bacteriochloro-

phyll, a corphin, a chlorophyllin, a bacteriochlorin, or an isobacteriochlorin complexed to an iron) and one or more flavor precursor molecules to form a mixture, the one or more flavor precursor molecules selected from the group consisting of glucose, fructose, arabinose, ribose glucose-6-phosphate, fructose 6-phosphate, fructose 1,6-diphosphate, inositol, maltose, sucrose, maltodextrin, glycogen, nucleotide-bound sugars, molasses, a phospholipid, a lecithin, inosine, inosine monophosphate (IMP), guanosine monophosphate (GMP), pyrazine, adenosine monophosphate (AMP), lactic acid, succinic acid, glycolic acid, thiamine, creatine, pyrophosphate, vegetable oil, algal oil, corn oil, soybean oil, palm fruit oil, palm kernel oil, safflower oil, flaxseed oil, rice bran oil, cottonseed oil, olive oil, sunflower oil, canola oil, flaxseed oil, coconut oil, mango oil, a free fatty acid, cysteine, methionine, isoleucine, leucine, lysine, phenylalanine, threonine, tryptophan, valine, arginine, histidine, alanine, asparagine, aspartate, glutamate, glutamine, glycine, proline, serine, tyrosine, glutathione, an amino acid derivative, a protein hydrolysate, a malt extract, a yeast extract, and a peptone; and heating the mixture to form one or more flavor compounds selected from the group consisting of phenylacetaldehyde, 1-octen-3-one, 2-n-heptylfuran, 2-thiophenecarboxaldehyde, 3-thiophenecarboxaldehyde, butyrolactone, 2-undecenal, pyrazine, methyl-, furfural, 2-decanone, pyrrole, 1-octen-3-ol, 2-acetylthiazole, (E)-2-octenal, decanal, benzaldehyde, (E)-2-nonenal, pyrazine, 1-hexanol, 1-heptanol, dimethyl trisulfide, 2-nonanone, 2-pentanone, 2-heptanone, 2,3-butanedione, heptanal, nonanal, 2-octanone, 1-octanol, 3-ethylcyclopentanone, 3-octen-2-one, (E,E)-2,4-heptadienal, (Z)-2-heptenal, 2-heptanone, 6-methyl-, (Z)-4-heptenal, (E,Z)-2,6-nonadienal, 3-methyl-2-butenal, 2-pentyl-furan, thiazole, (E,E)-2,4-decadienal, hexanoic acid, 1-ethyl-5-methylcyclopentene, (E,E)-2,4-nonadienal, (Z)-2-decenal, dihydro-5-pentyl-2(3H)-furanone, trans-3-nonen-2-one, (E,E)-3,5-octadien-2-one, (Z)-2-octen-1-ol, 5-ethyldihydro-2(3H)-furanone, 2-butenal, 1-penten-3-ol, (E)-2-hexenal, formic acid, heptyl ester, 2-pentyl-thiophene, (Z)-2-nonenal, 2-hexyl-thiophene, (E)-2-decenal, 2-ethyl-5-methyl-pyrazine, 3-ethyl-2,5-dimethyl-pyrazine, 2-ethyl-1-hexanol, thiophene, 2-methyl-furan, pyridine, butanal, 2-ethyl-furan, 3-methyl-butanal, trichloromethane, 2-methyl-butanal, methacrolein, 2-methyl-propanal, propanal, acetaldehyde, 2-propyl-furan, dihydro-5-propyl-2(3H)-furanone, 1,3-hexadiene, 4-decyne, pentanal, 1-propanol, heptanoic acid, trimethyl-ethanethiol, 1-butanol, 1-penten-3-one, dimethyl sulfide, 2-ethyl furan, 2-pentyl-thiophene, 2-propenal, 2-tridecen-1-ol, 4-octene, 2-methyl thiazole, methyl-pyrazine, 2-butanon, 2-pentyl-furan, 2-methyl-propanal, butyrolactone, 3-methyl-butanal, methyl-thiirane, 2-hexyl-furan, butanal, 2-methyl-butanal, 2-methyl-furan, furan, octanal, 2-heptenal, 1-octene, formic acid heptyl ester, 3-pentyl-furan, and 4-penten-2-one. The heme moiety can be a heme-containing protein, a heme moiety bound to a non-peptidic polymer; or a heme moiety bound to a solid support. The method can include combining cysteine, ribose, lactic acid, lysine, and/or thiamine with the heme-containing protein.

In another aspect, this document features a method for producing a flavor compound. The method includes combining an iron complex, such as a heme-containing protein, and one or more flavor precursor molecules to form a mixture, the one or more flavor precursor molecules selected from the group consisting of glucose, fructose, ribose, arabinose, glucose-6-phosphate, fructose 6-phosphate, fructose 1,6-diphosphate, inositol, maltose, sucrose, maltodextrin, glycogen, nucleotide-bound sugars, molasses, a phospholipid, a lecithin, inosine, IMP, GMP, pyrazine, AMP, lactic acid, succinic acid, glycolic acid, thiamine, creatine, pyrophosphate, sunflower oil, coconut oil, canola oil, flaxseed oil, mango oil, a free fatty acid, cysteine, methionine, isoleucine, leucine, lysine, phenylalanine, threonine, tryptophan, valine, arginine, histidine, alanine, asparagine, aspartate, glutamate, glutamine, glycine, proline, serine, tyrosine, glutathione, an amino acid derivative, a protein hydrolysate, a malt extract, a yeast extract, and a peptone; and heating the mixture.

pholipid, a lecithin, inosine, IMP, GMP, pyrazine, AMP, lactic acid, succinic acid, glycolic acid, thiamine, creatine, pyrophosphate, vegetable oil, algal oil, corn oil, soybean oil, palm fruit oil, palm kernel oil, safflower oil, flaxseed oil, rice bran oil, cottonseed oil, olive oil, sunflower oil, canola oil, flaxseed oil, coconut oil, mango oil, a free fatty acid, methionine, cysteine, isoleucine, leucine, lysine, phenylalanine, threonine, tryptophan, valine, arginine, histidine, alanine, asparagine, aspartate, glutamate, glutamine, glycine, proline, serine, tyrosine, glutathione, an amino acid derivative, a protein hydrolysate, a malt extract, a yeast extract, and a peptone; and heating the mixture to form one or more flavor compounds set forth in Tables 3, 8, or 9. For example, the flavor precursors can include cysteine, a sugar, and one or more other precursors.

This document also features a method for imparting a meat like flavor (e.g., beef-like, chicken like, pork-like, lamb-like, turkey-like, duck-like, deer-like, or bison-like) to a food product. The method includes contacting the food product with a flavoring composition, the flavoring composition comprising i) an iron complex, such as a heme moiety (e.g., a heme-containing protein); and ii) one or more flavor precursor molecules selected from the group consisting of glucose, fructose, ribose, arabinose, glucose-6-phosphate, fructose 6-phosphate, fructose 1,6-diphosphate, inositol, maltose, sucrose, maltodextrin, glycogen, nucleotide-bound sugars, molasses, a phospholipid, a lecithin, inosine, IMP, GMP, pyrazine, AMP, lactic acid, succinic acid, glycolic acid, thiamine, creatine, pyrophosphate, vegetable oil, algal oil, corn oil, soybean oil, palm fruit oil, palm kernel oil, safflower oil, flaxseed oil, rice bran oil, cottonseed oil, olive oil, sunflower oil, canola oil, flaxseed oil, coconut oil, mango oil, a free fatty acid, cysteine, methionine, isoleucine, leucine, lysine, phenylalanine, threonine, tryptophan, valine, arginine, histidine, alanine, asparagine, aspartate, glutamate, glutamine, glycine, proline, serine, tyrosine, glutathione, an amino acid derivative, a protein hydrolysate, a malt extract, a yeast extract, and a peptone; and heating the mixture to form one or more flavor compounds set forth in Tables 3, 8, or 9. For example, the flavor precursors can include cysteine, a sugar, and one or more other precursors.

This document also features a method for imparting a meat like flavor (e.g., beef-like, chicken like, pork-like, lamb-like, turkey-like, duck-like, deer-like, or bison-like) to a food product. The method includes contacting the food product with a flavoring composition, the flavoring composition comprising i) an iron complex, such as a heme moiety (e.g., a heme-containing protein); and ii) one or more flavor precursor molecules selected from the group consisting of glucose, fructose, ribose, arabinose, glucose-6-phosphate, fructose 6-phosphate, fructose 1,6-diphosphate, inositol, maltose, sucrose, maltodextrin, glycogen, nucleotide-bound sugars, molasses, a phospholipid, a lecithin, inosine, IMP, GMP, pyrazine, AMP, lactic acid, succinic acid, glycolic acid, thiamine, creatine, pyrophosphate, vegetable oil, algal oil, corn oil, soybean oil, palm fruit oil, palm kernel oil, safflower oil, flaxseed oil, rice bran oil, cottonseed oil, olive oil, sunflower oil, canola oil, flaxseed oil, coconut oil, mango oil, a free fatty acid, cysteine, methionine, isoleucine, leucine, lysine, phenylalanine, threonine, tryptophan, valine, arginine, histidine, alanine, asparagine, aspartate, glutamate, glutamine, glycine, proline, serine, tyrosine, glutathione, an amino acid derivative, a protein hydrolysate, a malt extract, a yeast extract, and a peptone; and heating the mixture to form one or more flavor compounds set forth in Tables 3, 8, or 9. For example, the flavor precursors can include cysteine, a sugar, and one or more other precursors.

This document also features a method for imparting a meat like flavor (e.g., beef-like, chicken like, pork-like, lamb-like, turkey-like, duck-like, deer-like, or bison-like) to a food product. The method includes contacting the food product with a flavoring composition, the flavoring composition comprising i) an iron complex, such as a heme moiety (e.g., a heme-containing protein); and ii) one or more flavor precursor molecules selected from the group consisting of glucose, fructose, ribose, arabinose, glucose-6-phosphate, fructose 6-phosphate, fructose 1,6-diphosphate, inositol, maltose, sucrose, maltodextrin, glycogen, nucleotide-bound sugars, molasses, a phospholipid, a lecithin, inosine, IMP, GMP, pyrazine, AMP, lactic acid, succinic acid, glycolic acid, thiamine, creatine, pyrophosphate, vegetable oil, algal oil, corn oil, soybean oil, palm fruit oil, palm kernel oil, safflower oil, flaxseed oil, rice bran oil, cottonseed oil, olive oil, sunflower oil, canola oil, flaxseed oil, coconut oil, mango oil, a free fatty acid, cysteine, methionine, isoleucine, leucine, lysine, phenylalanine, threonine, tryptophan, valine, arginine, histidine, alanine, asparagine, aspartate, glutamate, glutamine, glycine, proline, serine, tyrosine, glutathione, an amino acid derivative, a protein hydrolysate, a malt extract, a yeast extract, and a peptone; and heating the mixture to form one or more flavor compounds set forth in Tables 3, 8, or 9. For example, the flavor precursors can include cysteine, a sugar, and one or more other precursors.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this

invention pertains. Although methods and materials similar or equivalent to those described herein can be used to practice the invention, suitable methods and materials are described below. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims. The word "comprising" in the claims may be replaced by "consisting essentially of" or with "consisting of," according to standard practice in patent law.

#### DESCRIPTION OF THE DRAWINGS

FIG. 1 contains amino acid sequences of exemplary heme-containing proteins.

FIG. 2 is a bar graph of the beefiness rating of the meat replica with or without the Magic Mix, both samples in triplicate with 1% w/v LegH protein. Tasters rated beefiness on a scale from 1-7, with 1 being not beefy at all and 7 being exactly like ground beef.

#### DETAILED DESCRIPTION

This document is based on methods and materials for modulating the taste and/or aroma profile of food products. As described herein, compositions containing one or more flavor precursors and one or more highly conjugated heterocyclic rings complexed to an iron (referred to herein as an iron complex) can be used to modulate the taste and/or aroma profile of food products. Such iron complexes include heme moieties or other highly conjugated heterocyclic rings complexed to an iron ion (referred to as an iron complex). "Heme" refers to a prosthetic group bound to iron ( $\text{Fe}^{2+}$  or  $\text{Fe}^{3+}$ ) in the center of a porphyrin ring. Thus, an iron complex can be a heme moiety, or a porphyrin, porphyrinogen, corrin, corrinoid, chlorin, bacteriochlorophyll, corphin, chlorophyllin, bacteriochlorin, or isobacteriochlorin moiety complexed to iron ion. The heme moiety that can be used to modulate the taste and/or aroma profile of food products can be a heme cofactor such as a heme-containing protein; a heme moiety bound to a non-peptidic polymer or other macromolecule such as a liposome, a polyethylene glycol, a carbohydrate, a polysaccharide, a cyclodextrin, a polyethylenimine, a polyacrylate, or derivatives thereof; a siderophore (i.e., an iron chelating compound); or a heme moiety bound to a solid support (e.g., beads) composed of a chromatography resin, cellulose, graphite, charcoal, or diatomaceous earth.

In some embodiments, the iron complexes catalyze some reactions and produce flavor precursors without heating or cooking. In some embodiments, the iron complex destabilizes upon heating or cooking and releases the iron, e.g., the protein is denatured, so flavor precursors can be generated.

Suitable flavor precursors include sugars, sugar alcohols, sugar derivatives, oils (e.g., vegetable oils), free fatty acids, alpha-hydroxy acids, dicarboxylic acids, amino acids and derivatives thereof, nucleosides, nucleotides, vitamins, peptides, protein hydrolysates, extracts, phospholipids, lecithin, and organic molecules. Non-limiting examples of such flavor precursors are provided in Table 1.

TABLE 1

Flavor Precursor Molecules	
5	Sugars, sugar alcohols, sugar acids, and sugar derivatives: glucose, fructose, ribose, sucrose, arabinose, glucose-6-phosphate, fructose-6-phosphate, fructose 1,6-diphosphate, inositol, maltose, molasses, maltodextrin, glycogen, galactose, lactose, ribitol, gluconic acid and glucuronic acid, amylose, amylopectin, or xylose
10	Oils: coconut oil, mango oil, sunflower oil, cottonseed oil, safflower oil, rice bran oil, cocoa butter, palm fruit oil, palm oil, soybean oil, canola oil, corn oil, sesame oil, walnut oil, flaxseed, jojoba oil, castor, grapeseed oil, peanut oil, olive oil, algal oil, oil from bacteria or fungi
15	Free fatty acids: caprylic acid, capric acid, lauric acid, myristic acid, palmititic acid, palmitoleic acid, stearic, oleic acid, linoleic acid, alpha linolenic acid, gamma linolenic acid, arachidic acid, arachidonic acid, behenic acid, or erucic acid
20	Amino acids and derivatives thereof: cysteine, cystine, a cysteine sulfoxide, allicin, selenocysteine, methionine, isoleucine, leucine, lysine, phenylalanine, threonine, tryptophan, 5-hydroxytryptophan, valine, arginine, histidine, alanine, asparagine, aspartate, glutamate, glutamine, glycine, proline, serine, or tyrosine
25	Nucleosides and Nucleotides: inosine, inosine monophosphate (IMP), guanosine, guanoside monophosphate (GMP), adenosine, adenosine monophosphate (AMP)
30	Vitamins: thiamine, vitamin C, Vitamin D, Vitamin B6, or Vitamin E
35	Misc: phospholipid, lecithin, pyrazine, creatine, pyrophosphate
40	Acids: acetic acid, alpha hydroxy acids such as lactic acid or glycolic acid, tricarboxylic acids such as citric acid, dicarboxylic acids such as succinic acid or tartaric acid
45	Peptides and protein hydrolysates: glutathione, vegetable protein hydrolysates, soy protein hydrolysates, yeast protein hydrolysates, algal protein hydrolysates, meat protein hydrolysates
50	Extracts: a malt extract, a yeast extract, and a peptone

In some embodiments, one flavor precursor or combinations of two to one hundred flavor precursors, two to ninety, two to eighty, two to seventy, two to sixty, or two to fifty flavor precursors are used. For example, combinations of two to forty flavor precursors, two to thirty-five flavor precursors, two to ten flavor precursors, or two to six flavor precursors can be used with the one or more iron complexes (e.g., heme co-factors such as a heme-containing proteins). For example, the one or more flavor precursors can be glucose, ribose, cysteine, a cysteine derivative, thiamine, lysine, a lysine derivative, glutamic acid, a glutamic acid derivative, alanine, methionine, IMP, GMP, lactic acid, and mixtures thereof (e.g., glucose and cysteine; cysteine and ribose; cysteine, glucose or ribose, and thiamine; cysteine, glucose or ribose, IMP, and GMP; cysteine, glucose or ribose, and lactic acid). For example, the one or more flavor precursors can be alanine, arginine, asparagine, aspartate, cysteine, glutamic acid, glutamine, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, proline, threonine, tryptophan, tyrosine, valine, glucose, ribose, maltodextrin, thiamine, IMP, GMP, lactic acid, and creatine.

As used herein, the term "heme containing protein" can be used interchangeably with "heme containing polypeptide" or "heme protein" or "heme polypeptide" and includes any polypeptide that can covalently or noncovalently bind a heme moiety. In some embodiments, the heme-containing polypeptide is a globin and can include a globin fold, which comprises a series of seven to nine alpha helices. Globin type proteins can be of any class (e.g., class I, class II, or class III), and in some embodiments, can transport or store

oxygen. For example, a heme-containing protein can be a non-symbiotic type of hemoglobin or a leghemoglobin. A heme-containing polypeptide can be a monomer, i.e., a single polypeptide chain, or can be a dimer, a trimer, tetramer, and/or higher order oligomers. The life-time of the oxygenated Fe<sup>2+</sup> state of a heme-containing protein can be similar to that of myoglobin or can exceed it by 10%, 20%, 30% 50%, 100% or more under conditions in which the heme-protein-containing consumable is manufactured, stored, handled or prepared for consumption. The life-time of the unoxygengated Fe<sup>2+</sup> state of a heme-containing protein can be similar to that of myoglobin or can exceed it by 10%, 20%, 30% 50%, 100% or more under conditions in which the heme-protein-containing consumable is manufactured, stored, handled or prepared for consumption.

Non-limiting examples of heme-containing polypeptides can include an androglobin, a cytoglobin, a globin E, a globin X, a globin Y, a hemoglobin, a myoglobin, an erythrocrucorin, a beta hemoglobin, an alpha hemoglobin, a protoglobin, a cyanoglobin, a cytoglobin, a histoglobin, a neuroglobins, a chlorocruorin, a truncated hemoglobin (e.g., HbN or HbO), a truncated 2/2 globin, a hemoglobin 3 (e.g., Glb3), a cytochrome, or a peroxidase.

Heme-containing proteins that can be used in the compositions and food products described herein can be from mammals (e.g., farms animals such as cows, goats, sheep, pigs, ox, or rabbits), birds, plants, algae, fungi (e.g., yeast or filamentous fungi), ciliates, or bacteria. For example, a heme-containing protein can be from a mammal such as a farm animal (e.g., a cow, goat, sheep, pig, ox, or rabbit) or a bird such as a turkey or chicken. Heme-containing proteins can be from a plant such as *Nicotiana tabacum* or *Nicotiana sylvestris* (tobacco); *Zea mays* (corn), *Arabidopsis thaliana*, a legume such as *Glycine max* (soybean), *Cicer arietinum* (garbanzo or chick pea), *Pisum sativum* (pea) varieties such as garden peas or sugar snap peas, *Phaseolus vulgaris* varieties of common beans such as green beans, black beans, navy beans, northern beans, or pinto beans, *Vigna unguiculata* varieties (cow peas), *Vigna radiata* (Mung beans), *Lupinus albus* (lupin), or *Medicago sativa* (alfalfa); *Brassica napus* (canola); *Triticum* spp. (wheat, including wheat berries, and spelt); *Gossypium hirsutum* (cotton); *Oryza sativa* (rice); *Zizania* spp. (wild rice); *Helianthus annuus* (sunflower); *Beta vulgaris* (sugarbeet); *Pennisetum glaucum* (pearl millet); *Chenopodium* sp. (quinoa); *Sesamum* sp. (sesame); *Linum usitatissimum* (flax); or *Hordeum vulgare* (barley). Heme-containing proteins can be isolated from fungi such as *Saccharomyces cerevisiae*, *Pichia pastoris*, *Magnaporthe oryzae*, *Fusarium graminearum*, *Aspergillus oryzae*, *Trichoderma reesei*, *Mycelopthora thermophile*, *Kluyvera lactis*, or *Fusarium oxysporum*. Heme-containing proteins can be isolated from bacteria such as *Escherichia coli*, *Bacillus subtilis*, *Bacillus licheniformis*, *Bacillus megaterium*, *Synechocystis* sp., *Aquifex aeolicus*, *Methylacidiphilum infernorum*, or thermophilic bacteria such as *Thermophilus*. The sequences and structure of numerous heme-containing proteins are known. See for example, Reedy, et al., *Nucleic Acids Research*, 2008, Vol. 36, Database issue D307-D313 and the Heme Protein Database Available on the world wide web at [hemeprotein.info/heme.php](http://hemeprotein.info/heme.php).

For example, a non-symbiotic hemoglobin can be from a plant selected from the group consisting of soybean, sprouted soybean, alfalfa, golden flax, black bean, black eyed pea, northern, garbanzo, moong bean, cowpeas, pinto beans, pod peas, quinoa, sesame, sunflower, wheat berries, spelt, barley, wild rice, or rice.

Any of the heme-containing proteins described herein that can be used for producing food products can have at least 70% (e.g., at least 75%, 80%, 85%, 90%, 95%, 97%, 98%, 99%, or 100%) sequence identity to the amino acid sequence 5 of the corresponding wild-type heme-containing protein or fragments thereof that contain a heme-binding motif. For example, a heme-containing protein can have at least 70% sequence identity to an amino acid sequence set forth in FIG. 1, including a non-symbiotic hemoglobin such as that from 10 *Vigna radiata* (SEQ ID NO:1), *Hordeum vulgare* (SEQ ID NO:5), *Zea mays* (SEQ ID NO:13), *Oryza sativa* subsp. *japonica* (rice) (SEQ ID NO:14), or *Arabidopsis thaliana* (SEQ ID NO:15), a Hell's gate globin I such as that from *Methylacidiphilum infernorum* (SEQ ID NO:2), a flavohemoprotein such as that from *Aquifex aeolicus* (SEQ ID NO:3), a leghemoglobin such as that from *Glycine max* (SEQ ID NO:4), *Pisum sativum* (SEQ ID NO:16), or *Vigna unguiculata* (SEQ ID NO:17), a heme-dependent peroxidase such as from *Magnaporthe oryzae*, (SEQ ID NO:6) or 20 *Fusarium oxysporum* (SEQ ID NO:7), a cytochrome c peroxidase from *Fusarium graminearum* (SEQ ID NO:8), a truncated hemoglobin from *Chlamydomonas moewusii* (SEQ ID NO:9), *Tetrahymena pyriformis* (SEQ ID NO:10, group I truncated), *Paramecium caudatum* (SEQ ID NO:11, group I truncated), a hemoglobin from *Aspergillus niger* (SEQ ID NO:12), or a mammalian myoglobin protein such as the *Bos taurus* (SEQ ID NO:18) myoglobin, *Sus scrofa* (SEQ ID NO:19) myoglobin, *Equus caballus* (SEQ ID NO:20) myoglobin, a heme-protein from *Nicotiana benthamiana* (SEQ ID NO:21), *Bacillus subtilis* (SEQ ID NO:22), *Corynebacterium glutamicum* (SEQ ID NO:23), *Synechocystis PCC6803* (SEQ ID NO:24), *Synechococcus* sp. PCC 7335 (SEQ ID NO:25), or *Nostoc commune* (SEQ ID NO:26).

The percent identity between two amino acid sequences can be determined as follows. First, the amino acid sequences are aligned using the BLAST 2 Sequences (B12seq) program from the stand-alone version of BLASTZ containing BLASTP version 2.0.14. This stand-alone version of BLASTZ can be obtained from Fish & Richardson's web site (e.g., [www.fr.com/blast/](http://www.fr.com/blast/)) or the U.S. government's National Center for Biotechnology Information web site ([www.ncbi.nlm.nih.gov](http://www.ncbi.nlm.nih.gov)). Instructions explaining how to use the B12seq program can be found in the readme file accompanying BLASTZ. B12seq performs a comparison between two amino acid sequences using the BLASTP algorithm. To compare two amino acid sequences, the options of B12seq are set as follows: -i is set to a file containing the first amino acid sequence to be compared (e.g., C:\seq1.txt); -j is set to 35 a file containing the second amino acid sequence to be compared (e.g., C:\seq2.txt); -p is set to blastp; -o is set to any desired file name (e.g., C:\output.txt); and all other options are left at their default setting. For example, the following command can be used to generate an output file 40 containing a comparison between two amino acid sequences: C:\B12seq -i c:\seq1.txt -j c:\seq2.txt -p blastp -o c:\output.txt. If the two compared sequences share homology, then the designated output file will present those regions of homology as aligned sequences. If the two 45 compared sequences do not share homology, then the designated output file will not present aligned sequences. Similar procedures can be followed for nucleic acid sequences 50 except that blastn is used.

Once aligned, the number of matches is determined by 55 counting the number of positions where an identical amino acid residue is presented in both sequences. The percent identity is determined by dividing the number of matches by

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the length of the full-length polypeptide amino acid sequence followed by multiplying the resulting value by 100. It is noted that the percent identity value is rounded to the nearest tenth. For example, 78.11, 78.12, 78.13, and 78.14 is rounded down to 78.1, while 78.15, 78.16, 78.17, 78.18, and 78.19 is rounded up to 78.2. It also is noted that the length value will always be an integer.

It will be appreciated that a number of nucleic acids can encode a polypeptide having a particular amino acid sequence. The degeneracy of the genetic code is well known to the art; i.e., for many amino acids, there is more than one nucleotide triplet that serves as the codon for the amino acid. For example, codons in the coding sequence for a given enzyme can be modified such that optimal expression in a particular species (e.g., bacteria or fungus) is obtained, using appropriate codon bias tables for that species.

Heme-containing proteins can be extracted from the source material (e.g., extracted from animal tissue, or plant, fungal, algal, or bacterial biomass, or from the culture supernatant for secreted proteins) or from a combination of source materials (e.g., multiple plant species). Leghemoglobin is readily available as an unused by-product of commodity legume crops (e.g., soybean, alfalfa, or pea). The amount of leghemoglobin in the roots of these crops in the United States exceeds the myoglobin content of all the red meat consumed in the United States.

In some embodiments, extracts of heme-containing proteins include one or more non-heme-containing proteins from the source material (e.g., other animal, plant, fungal, algal, or bacterial proteins) or from a combination of source materials (e.g., different animal, plant, fungi, algae, or bacteria).

In some embodiments, heme-containing proteins are isolated and purified from other components of the source material (e.g., other animal, plant, fungal, algal, or bacterial proteins). As used herein, the term "isolated and purified" indicates that the preparation of heme-containing protein is at least 60% pure, e.g., greater than 65%, 70%, 75%, 80%, 85%, 90%, 95%, or 99% pure. Without being bound by theory, isolating and purifying proteins can allow the food products to be made with greater consistency and greater control over the properties of the food product as unwanted material is eliminated. Proteins can be separated on the basis of their molecular weight, for example, by size exclusion chromatography, ultrafiltration through membranes, or density centrifugation. In some embodiments, the proteins can be separated based on their surface charge, for example, by isoelectric precipitation, anion exchange chromatography, or cation exchange chromatography. Proteins also can be separated on the basis of their solubility, for example, by ammonium sulfate precipitation, isoelectric precipitation, surfactants, detergents or solvent extraction. Proteins also can be separated by their affinity to another molecule, using, for example, hydrophobic interaction chromatography, reactive dyes, or hydroxyapatite. Affinity chromatography also can include using antibodies having specific binding affinity for the heme-containing protein, nickel NTA for His-tagged recombinant proteins, lectins to bind to sugar moieties on a glycoprotein, or other molecules which specifically binds the protein.

Heme-containing proteins also can be recombinantly produced using polypeptide expression techniques (e.g., heterologous expression techniques using bacterial cells, insect cells, fungal cells such as yeast, plant cells such as tobacco, soybean, or *Arabidopsis*, or mammalian cells). In some cases, standard polypeptide synthesis techniques (e.g., liquid-phase polypeptide synthesis techniques or solid-phase

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polypeptide synthesis techniques) can be used to produce heme-containing proteins synthetically. In some cases, in vitro transcription-translation techniques can be used to produce heme-containing proteins.

The protein used in the consumable may be soluble in a solution. In some embodiments, the isolated and purified proteins are soluble in solution at greater than 5, 10, 15, 20, 25, 50, 100, 150, 200, or 250 g/L.

In some embodiments, the isolated and purified protein is substantially in its native fold and water soluble. In some embodiments, the isolated and purified protein is more than 50, 60, 70, 80, or 90% in its native fold. In some embodiments, the isolated and purified protein is more than 50, 60, 70, 80, or 90% water soluble.

In some embodiments, the food product contains between 0.01% and 5% by weight of a heme protein. In some embodiments, the food product contains between 0.01% and 5% by weight of leghemoglobin. Some meat also contains myoglobin, a heme protein, which accounts for most of the red color and iron content of some meat. It is understood that these percentages can vary in meat and the food products can be produced to approximate the natural variation in meat.

In some embodiments, the food product comprises about 0.05%, about 0.1%, about 0.2%, about 0.3%, about 0.4%, about 0.5%, about 0.6%, about 0.7%, about 0.8%, about 0.9%, about 1.1%, about 1.2%, about 1.3%, about 1.4%, about 1.5%, about 1.6%, about 1.7%, about 1.8%, about 1.9%, about 2%, or more than about 2% of an iron-carrying protein (e.g., a heme-containing protein) by dry weight or total weight. In some cases, the iron carrying protein has been isolated and purified from a source.

## Modulating Flavor and/or Aroma Profiles

As described herein, different combinations of flavor precursors can be used with one or more iron complexes (e.g., a ferrous chlorin, a chlorin-iron complex, or a heme-cofactor such as a heme-containing protein or heme bound to a non-peptidic polymer such as polyethylene glycol or to a solid support) to produce different flavor and aroma profiles when the flavor precursors and iron complexes are heated together (e.g., during cooking). The resultant flavor and/or aroma profile can be modulated by the type and concentration of the flavor precursors, the pH of the reaction, the length of cooking, the type and amount of iron complex (e.g., a heme-cofactor such as heme-containing protein, heme bound to non-peptidic polymer or macromolecule, or heme bound to a solid support), the temperature of the reaction, and the amount of water activity in the product, among other factors. In embodiments in which a heme moiety is bound to a solid support such as cellulose or a chromatography resin, graphite, charcoal, or diatomaceous earth, the solid support (e.g., beads) can be incubated with sugars and/or one or more other flavor precursors to generate flavors, and then the solid support with attached heme moiety can be re-used, i.e., incubated again with sugars and/or one or more other flavor precursors to generate flavors.

Table 2 provides non-limiting examples of flavor types that can be generated by combining one or more flavor precursors and one or more heme co-factors (e.g., heme-containing proteins). See also Tables 7 and/or 11.

TABLE 2

Flavor Types	
beef beef dripping	beef broth cheesy

TABLE 2-continued

Flavor Types	
cold-cut deli meat	squash
bacon	sharp
meaty	fruity
brothy	floral
ramen	musty
egg	fried food
malty	caramel
bready	barbecue
sulfur	chocolate
fried chicken	sweet
browned	potato
pretzel	french toast
grassy	breadcrust
bloody	mushroom
broccoli	chicken
brothy	cumin
buttery	umami
metallic	raisin
yeasty	goaty
vegetable broth	

Flavor and aroma profiles are created by different chemical compounds formed by chemical reactions between the heme co-factor (e.g., heme-containing protein) and flavor precursors. Gas chromatography—mass spectrometry (GCMS) can be used to separate and identify the different chemical compounds within a test sample. For example, volatile chemicals can be isolated from the head space after heating a heme-containing protein and one or more flavor precursors.

Table 3 provides non-limiting examples of compounds that can be produced. See also Tables 8, 9, 12, and/or 14.

TABLE 3

Compounds Produced		
phenylacetaldehyde	2-butenal, 2-ethyl-acetonitrile	1,3-hexadiene
1-octen-3-one		4-decyne
2-n-heptylfuran		pentanal
2-thiophenecarboxaldehyde	(E)-2-Hexenal	1-propanol
3-thiophenecarboxaldehyde	4-ethyl-phenol,	heptanoic acid
1-octene	3-octanone	ethanethiol
butyrolactone	styrene	2-methyl-1-heptene
2-undecenal	furan, 3-pentyl-formic acid, heptyl ester	(E)-4-octene
propyl-cyclopropane		2-methyl-2-heptene
methyl-pyrazine	(E)-2-Heptenal	pentanoic acid
1-hydroxy-propanone	6-methyl-5-hepten-2-one	nonanoic acid
acetic acid	n-caproic acid vinyl ester	1,3-dimethyl-benzene
furfural	2ethyl-2-hexenal	
2-decanone	1-hepten-3-ol	toluene
pyrrole	1-ethyl-1-methyl-cyclopentane	1-butanol
1-octen-3-ol	3-ethyl-2-methyl-1,3-hexadiene	2,3,3-trimethyl-pentane
2-acetylthiazole	2-pentyl-thiophene	isopropyl alcohol
(E)-2-octenal	(Z)-2-nonenal	2,2,4,6,6-pentamethyl-heptane
decanal	2-n-octylfuran	phenol
benzaldehyde	2-hexyl-thiophene	1-penten-3-one
(E)-2-Nonenal	4-cyclopentene-1,3-dione	dimethyl sulfide
pyrazine	1-nonanol	thiirane
1-pentanol	(E)-2-decenal	(E)-2-octen-1-ol
trans-2-(2-pentenyl)furan	4-ethyl-benzaldehyde	2,4-dimethyl-1-heptene
1-hexanol	1,7-octadien-3-ol	1,3-bis(1,1-dimethyl-ethyl)-benzene
1-heptanol	octanoic acid	heptane
dimethyl trisulfide	2-ethyl-5-methyl-pyrazine	4,7-dimethyl-undecane

TABLE 3-continued

Compounds Produced		
2-nonanone	3-ethyl-2,5-dimethyl-pyrazine	acetophenone
5	2-pentanone	1,3,5-cycloheptatriene
	2-heptanone	2-ethyl-1-hexanol
	2,3-butanedione	4-methyl-octanoic acid
	heptanal	m-aminophenylacetylene
10	nonanal	benzene
	2-octanone	thiophene
	2-butanon	2-methyl-furan
15	octanal	pyridine
	1-octanol	furan
	3-ethylcyclopentanone	butanal
	8-methyl-1-undecene	2-ethyl-furan
20	3-octen-2-one	carbon disulfide
	2,4-Heptadien, (E,E)-(Z)-2-heptenal	Furan, 2-hexyl-2-3-methyl-butanal
	6-methyl-2-heptanone	2-methyl-butanal
	(Z)-4-heptenal	methacrolein
25	(E,Z)-2,6-nonadien	octane
	3-methyl-2-butenal	ethanol
	2-pentyl-furan	2-methyl-propanal
	thiazole	acetone
	(E,E)-2,4-decadien	propanal
30	hexanoic acid	methyl-thiirane
	1-ethyl-5-methylcyclopentene	acetaldehyde
	(E,E)-2,4-nonadien	2-propenal
	(Z)-2-decenal	2-propyl-furan
	dihydro-5-pentyl-2(3h)-furanone	dihydro-5-propyl-2(3H)-furanone
35	trans-3-nonen-2-one	dihydro-3-(2H)-thiophenone
	(E,E)-3,5-octadien-2-one	2,2,6-trimethyl-decane
	(Z)-2-octen-1-ol	3,3'-dithiobis[2-methyl-furan]
	5-ethylidihydro-2(3h)-furanone	1-heptene
40	2-butenal	1,3-octadiene
	1-penten-3-ol	1-nonen
	1-(ethylthio)-2-(methylthio)-buta-1,3-diene	1-heptene
45		1,2-benzisothiazol-3(2H)-one
		2-acetyl-propen-2-ol, 1-decen-3-one
		2-methyl-heptane
		2-methyl-3-furanthiol
		4-amino-1,2,5-carbonitrile
		1,2-benzisothiazol-3(2H)-one
		2-acetyl-propen-2-ol, 1-decen-3-one

In some embodiments, an iron complex (e.g., a ferrous chlorin or a heme-cofactor such as a heme-containing protein) described herein is heated in the presence of ground chicken, to increase specific volatile flavor and odorant components typically elevated in beef. For example, propanal, butanal, 2-ethyl-furan, heptanal, octanal, trans-2-(2-pentenyl)furan, (Z)-2-heptenal, (E)-2-octenal, pyrrole, 2,4-dodecadienal, 1-octanal, (Z)-2-decenal, or 2-undecenal can be increased in the presence of the heme-containing protein, which can impart a more beefy flavor to the chicken.

In some embodiments, an iron complex (e.g., a ferrous chlorin or a heme-cofactor such as a heme-containing protein) described herein is heated in the presence of cysteine and glucose or other combinations of flavor precursors to provide a different profile of volatile odorants than when any subset of the three components are used individually. Volatile flavor components that are increased under these conditions include but are not limited to furan, acetone, thiazole, furfural, benzaldehyde, 2-pyridinecarboxaldehyde, 5-methyl-2-thiophenecarboxaldehyde, 3-methyl-2-thio-

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phenecarboxaldehyde, 3-thiophenemethanol and decanol. See, e.g., Tables 8 and 9. Under these conditions, cysteine and glucose alone or in the presence of iron salts such as ferrous glucanate produced a sulfurous, odor, but addition of heme-containing proteins reduced the sulfurous odor and replaced it with flavors including but not limited to chicken broth, burnt mushroom, molasses, and bread.

In some embodiments, an iron complex (e.g., a ferrous chlorin or a heme-cofactor such as a heme-containing protein) described herein is heated in the presence of cysteine and ribose to provide a different profile of volatile odorants. Heating in the presence of ribose created some additional compounds as compared to when a heme-containing protein and glucose were heated together. See Tables 8 and 9.

In some embodiments, an iron complex (e.g., a ferrous chlorophillin or a heme-cofactor such as a heme-containing protein) described herein can be heated in the presence of thiamine and a sugar to affect the formation of 5-Thiazoleethanol, 4-methyl-furan, 3,3'-dithiobis[2-methyl-furan, and/or 4-Methylthiazole. These compounds are known to be present in meat and have beefy, meaty taste notes.

In some embodiments, an iron complex (e.g., a ferrous chlorin or a heme-cofactor such as a heme-containing protein) described herein can be heated in the presence of a nucleotide such as inosine monophosphate and/or guanosine monophosphate to control the formation of flavor compounds such as (E)-4-octene, 2-ethyl-furan, 2-pentanone, 2,3-butanedione, 2-methyl-thiazole, methyl-pyrazine, tridecane, (E)-2-octenal, 2-thiopenecarboxaldehyde, and/or 3-thiopenecarboxaldehyde. These compounds are known to be present in meat and have a beefy, meaty, buttery, and or savory flavor notes.

In some embodiments, an iron complex (e.g., a ferrous chlorin or a heme-cofactor such as a heme-containing protein) described herein can be heated in the presence of lysine, a sugar such as ribose, and cysteine to control the formation of flavor compounds such as dimethyl trisulfide, nonanal, 2-pentyl thiophene, 2-nonenal furfural, 1-octanol, 2-nonenal, thiazole, 2-acetylthiazole, phenylacetaldehyde, and/or 2-acetylthiazole. These compounds are known to be present in meat and some have a beefy, meaty, and or savory flavor.

In some embodiments, an iron complex (e.g., a ferrous chlorin or a heme-cofactor such as a heme-containing protein) described herein can be heated in the presence of lactic acid, a sugar such as ribose, and cysteine to control the formation of the flavor compounds nonanal, thiazole, 2-acetylthiazole, and/or 8-methyl 1-undecene. These compounds are known to be present in meat and have beefy, savory, browned, bready, and malty notes.

In some embodiments, an iron complex (e.g., a ferrous chlorin or a heme-cofactor such as a heme-containing protein) described herein can be heated in the presence of amino acids, sugars such as glucose, ribose, and maltodextrin, lactic acid, thiamine, IMP, GMP, creatine, and salts such as potassium chloride and sodium chloride, to control the formation of flavor compounds such as 1,3-bis(1,1-dimethyl-ethyl)-benzene, 2-methyl 3-furanthiol, and/or bis(2-methyl-4,5-dihydro-3-furyl)disulfide. These compounds are known to be present in meat and have beefy notes. See also Table 14.

In some embodiments, a particular type of heme-containing protein is chosen to control the formation of flavor compounds. See, for example, the results of Table 9, which shows that the addition of different types of heme-proteins (*LegH*, Barley, *B. myoglobin*, or *A. aeolicus*) in flavor reaction mixtures containing one or more flavor precursor

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compounds results in many of the same key meat flavors, including but not limited to pentanone, 3-methyl butanal, 2-methyl butanal, 2-heptenal, 1-octene, nonanal, 2-propenal, 2-decenal, 2-nonanone, 2-octanone, 2-tridecen-1-ol, 2-octanone, 2-octenal, 4-methyl-2-heptanone, octanal, 2-undecenal, butyrolactone, 1-octen-3-one, 3-methylheptyl acetate, and 2-pentyl-thiophene. These differences in flavor compounds can change the overall taste profile.

In some embodiments, an iron complex (e.g., a ferrous chlorin or a heme-cofactor such as a heme-containing protein) described herein and one or more flavor precursors can be reacted (e.g., in vitro) with heating to generate a particular flavor and/or aroma profile of interest and the resultant flavor additive composition can be added to the consumable food product of interest, which can then be eaten as-is or can be additionally modified, e.g., by additional cooking.

In some embodiments, any undesirable flavors can be minimized by deodorizing with activated charcoal or by removing enzymes such as lipoxygenases (LOX), which can be present in trace amounts when using preparations of plant proteins, and which can convert unsaturated triacylglycerides (such as linoleic acid or linolenic acid) into smaller and more volatile molecules. LOX are naturally present in legumes such as peas, soybeans, and peanuts, as well as rice, potatoes, and olives. When legume flours are fractionated into separate protein fractions, LOX can act as undesirable “time-bombs” that can cause undesirable flavors on aging or storage. Compositions containing plant proteins (e.g., from ground plant seeds) can be subjected to purification to remove LOX using, for example, an affinity resin that binds to LOX and removes it from the protein sample. The affinity resin can be linoleic acid, linolenic acid, stearic acid, oleic acid, propyl gallate, or epigallocatechin gallate attached to a solid support such as a bead or resin. See, e.g., WO2013138793. In addition, depending on the protein component of the food product, certain combinations of antioxidants and/or LOX inhibitors can be used as effective agents to minimize off-flavor or off-odor generation especially in the presence of fats and oils. Such compounds can include, for example, one or more of  $\beta$ -carotene,  $\alpha$ -tocopherol, caffeic acid, propyl gallate, or epigallocatechin gallate.

In some embodiments, specific flavor compounds, such as those described in Tables 3, 8, 9, 12, 14, 16, or 17 can be isolated and purified from the flavor additive composition. These isolated and purified compounds can be used as an ingredient to create flavors useful to the food and fragrance industry.

A flavor additive composition can be in the form, of but not limited to, soup or stew bases, bouillon, e.g., powder or cubes, flavor packets, or seasoning packets or shakers. Such flavor additive compositions can be used to modulate the flavor and/or aroma profile for a variety of food products, and can be added to a consumable food product before, during, or after cooking of the food product.

## Food Products

Food products containing one or more flavor precursors and one or more heme-containing proteins can be used as a base for formulating a variety of additional food products, including meat substitutes, soup bases, stew bases, snack foods, bouillon powders, bouillon cubes, flavor packets, or frozen food products. Meat substitutes can be formulated, for example, as hot dogs, burgers, ground meat, sausages, steaks, filets, roasts, breasts, thighs, wings, meatballs, meatloaf, bacon, strips, fingers, nuggets, cutlets, or cubes.

In addition, food products described herein can be used to modulate the taste and/or aroma profile of other food products (e.g., meat replicas, meat substitutes, tofu, mock duck

or other gluten based vegetable product, textured vegetable protein such as textured soy protein, pork, fish, lamb, or poultry products such as chicken or turkey products) and can be applied to the other food product before or during cooking. Using the food products described herein can provide a particular meaty taste and smell, for example, the taste and smell of beef or bacon, to a non-meat product or to a poultry product.

Food products described herein can be packaged in various ways, including being sealed within individual packets or shakers, such that the composition can be sprinkled or spread on top of a food product before or during cooking.

Food products described herein can include additional ingredients including food-grade oils such as canola, corn, sunflower, soybean, olive or coconut oil, seasoning agents such as edible salts (e.g., sodium or potassium chloride) or herbs (e.g., rosemary, thyme, basil, sage, or mint), flavoring agents, proteins (e.g., soy protein isolate, wheat gluten, pea vicilin, and/or pea legumin), protein concentrates (e.g., soy protein concentrate), emulsifiers (e.g., lecithin), gelling agents (e.g., k-carrageenan or gelatin), fibers (e.g., bamboo fiber or inulin), or minerals (e.g., iodine, zinc, and/or calcium).

Food products described herein also can include a natural coloring agent such as turmeric or beet juice, or an artificial coloring agent such as azo dyes, triphenylmethanes, xanthenes, quinines, indigoids, titanium dioxide, red #3, red #40, blue #1, or yellow #5.

Food products described herein also can include meat shelf life extenders such as carbon monoxide, nitrites, sodium metabisulfite, Bombal, vitamin E, rosemary extract, green tea extract, catechins and other anti-oxidants.

Food products described herein can be free of animal products (e.g., animal heme-containing proteins or other animal products).

In some embodiments, the food products can be soy-free, wheat-free, yeast-free, MSG-free, and/or free of protein hydrolysis products, and can taste meaty, highly savory, and without off odors or flavors.

#### Assessment of Food Products

Food products described herein can be assessed using trained human panelists. The evaluations can involve eyeing, feeling, chewing, and tasting of the product to judge product appearance, color, integrity, texture, flavor, and mouth feel, etc. Panelists can be served samples under red or under white light. Samples can be assigned random three-digit numbers and rotated in ballot position to prevent bias. Sensory judgments can be scaled for "acceptance" or "likeability" or use special terminology. For example, letter scales (A for excellent, B for good, C for poor) or number scales may be used (1=dislike, 2=fair, 3=good; 4=very good; 5=excellent). A scale can be used to rate the overall acceptability or quality of the food product or specific quality attributes such as beefiness, texture, and flavor. Panelists can be encouraged to rinse their mouths with water between samples, and given opportunity to comment on each sample.

In some embodiments, a food product described herein can be compared to another food product (e.g., meat or meat substitute) based upon olfactometer readings. In various embodiments, the olfactometer can be used to assess odor concentration and odor thresholds, odor suprathresholds with comparison to a reference gas, hedonic scale scores to determine the degree of appreciation, or relative intensity of odors.

In some embodiments, an olfactometer allows the training and automatic evaluation of expert panels. In some embodiments, a food product described herein causes similar or

identical olfactometer readings. In some embodiments, the differences between flavors generated using the methods of the invention and meat are sufficiently small to be below the detection threshold of human perception.

5 In some embodiments, volatile chemicals identified using GCMS can be evaluated. For example, a human can rate the experience of smelling the chemical responsible for a certain peak. This information could be used to further refine the profile of flavor and aroma compounds produced using a heme-containing protein and one or more flavor precursors.

10 Characteristic flavor and fragrance components are mostly produced during the cooking process by chemical reactions molecules including amino acids, fats and sugars which are found in plants as well as meat. Therefore, in some 15 embodiments, a food product is tested for similarity to meat during or after cooking. In some embodiments human ratings, human evaluation, olfactometer readings, or GCMS measurements, or combinations thereof, are used to create an olfactory map of the food product. Similarly, an olfactory 20 map of the food product, for example, a meat replica, can be created. These maps can be compared to assess how similar the cooked food product is to meat.

25 In some embodiments, the olfactory map of the food product during or after cooking is similar to or indistinguishable from that of cooked or cooking meat. In some 30 embodiments the similarity is sufficient to be beyond the detection threshold of human perception. The food product can be created so its characteristics are similar to a food product after cooking, but the uncooked food product may have properties that are different from the predicate food product prior to cooking.

35 These results will demonstrate that the compositions of the invention are judged as acceptably equivalent to real meat products. Additionally, these results can demonstrate that compositions of the invention are preferred by panelist over other commercially available meat substitutes. So, in 40 some embodiments the present invention provides for consumables that are significantly similar to traditional meats and are more meat like than previously known meat alternatives.

The invention will be further described in the following examples, which do not limit the scope of the invention described in the claims.

#### EXAMPLES

##### Example 1: Addition of Heme-Protein Increases Beefy Qualities of Replica Burgers

50 Replica burgers containing the ingredients in Table 4 and the flavor precursors cysteine (10 mM), glutamic acid (10 mM), glucose (10 mM), and thiamine (1 mM) were prepared. Water was added to make up the balance. See, for example, U.S. Provisional Application No. 61/751,816, filed Jan. 11, 2013. Control burgers were prepared as in Table 4 with precursors cysteine (10 mM), glutamic acid (10 mM), glucose (10 mM), and thiamine (1 mM) except LegH was omitted.

55 After cooking for 5 minutes at 150 C, the replica burgers were evaluated by a trained sensory panel. Panelists were served samples under red lights and each panelist individually evaluated the samples. Samples were assigned a random three-digit number and rotated in ballot position to prevent bias. Panelists were asked to evaluate cooked replica burger samples on multiple flavor, aroma, taste, texture and appearance attributes including but not limited to: beefiness, bloody quality, savory quality, and overall acceptability

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using a 7-point scale from 1=dislike extremely, to 7=like extremely. Panelists were encouraged to rinse their mouths with water between samples, and to fill out a survey to record their evaluation of each sample.

When replica burgers containing the LegH were compared to the control replica burgers without LegH, the samples containing LegH were rated significantly beefier, bloodier, more savory, and overall preferred compared to those that did not include LegH. See Table 5.

TABLE 4

Replica Burger Ingredients	
Replica burger	% precooked w/w
Pea vicilin	3.86
Soy protein concentrate (SPC)	2.52
Bamboo fiber	0.34
NaCl	0.54
Pea legumin	2
Soy Protein Isolate (SPI) (Solae, St. Louis, MO)	4.68
Wheat gluten	4.68
Coconut oil	15
Soy lecithin	0.1
k-carrageenan	1
LegH	1

TABLE 5

Sensory evaluation of replica burger with Heme			
Attribute	Beef 20/80	No Heme	1% Heme
<u>Beefyness</u>			
mean	5.33	1.30	3.20
STDEV	1.58	0.67	0.79
<u>Bloody</u>			
mean	4.00	1.10	2.78
STDEV	1.32	0.32	1.64
<u>Savory</u>			
mean	4.67	3.00	5.10
STDEV	1.22	1.63	0.57

#### Example 2: Replica Burgers with a Flavor Precursor Mixture Taste Beefy and Bloody

Replica burgers containing a flavor precursor mixture of glucose, cysteine, thiamine, and glutamic acid and 1% LegH

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pre-cooked w/w (see Table 4) were prepared as described in Example 1, and evaluated by a trained sensory panel after the burgers were cooked for 5 minutes at 150 C. Control burgers included LegH and all other ingredients except for the flavor precursor mixture.

Panelists were asked to evaluate the samples overall improvement in taste and descriptively analyze each sample using a 5-point scale from 1=dislike extremely, to 5=like extremely. Panelists were encouraged to rinse their mouths with water between samples, and to fill out a survey to record their evaluation of each sample. The replicate burgers which included LegH and the flavor precursor mixture were described as having bouillon, gravy, meaty, bloody, savory, and beefy notes on taste, and were preferred to the same replica burger with LegH but no added flavor precursor mixture. See, Table 6

TABLE 6

Improvement of overall taste with precursors added to LegH burgers		
	with precursors	without precursors
Average	3.5	1.8
STDV	0.6	0.5

#### Example 3: Replica Burgers with Flavor Precursor Mixture Resulting in a Bacon Taste

Replica burgers (see Table 4) were cooked with different precursor mixes (see Table 7) and 1% LegH and evaluated by a trained sensory panel after the burgers were cooked for 5 minutes at 150 C. Control burgers contained LegH and all of the other ingredients except for the flavor precursors. Panelists were asked to evaluate each sample and descriptively analyze each sample. 5-point scale from 1=dislike extremely, to 5=like extremely. Panelists were encouraged to rinse their mouths with water between samples, and to fill out a survey to record their evaluation of each sample. A replica burger with a precursor mixture of 10 mM glucose, 10 mM ribose, 10 mM cysteine, 1 mM thiamine, 1 mM glutamic acid, 1 mM GMP, and LegH was described as having a bacon aroma and taste, and overall meatiness, savory quality, a very umami quality, a brothy quality, and slight beefy notes. See Table 7 for a summary of the flavor description for the various combinations of flavor precursors and heme-containing protein.

TABLE 7

Flavors generated by addition of precursors to LegH (1%)			
Precursor (concentration)		Flavor Description	
ribose (10 mM)	cysteine (10 mM)		some kind of cold-cut/sliced deli meat
ribose (10 mM)	cysteine (10 mM)	IMP (2 mM)	bread crust with beef drippings, sweet, grassy, umami
ribose (10 mM)	cysteine (10 mM)	lactic acid (1 mM)	bready, malty, browned, breadcrust
ribose (10 mM)	cysteine (10 mM)	lysine (5 mM)	savory, beefy, little grassy, brothy, bread
ribose (10 mM)	cysteine (10 mM)	alanine (5 mM)	savory, weak beefy, brothy, little metallic
ribose (10 mM)	cysteine (10 mM)	I + G (2 mM)	savory, weak beefy, brothy, sweet

TABLE 7-continued

Flavors generated by addition of precursors to LegH (1%)						
	Precursor (concentration)		Flavor Description			
ribose (10 mM)	cysteine (10 mM)		methionine	cooked potato		
ribose (10 mM)	cysteine (10 mM)	glutamic acid (5 mM)		little meaty, pretzel, brothy, savory, sweet, chocolate		
glucose (10 mM)	ribose (10 mM)	cysteine (10 mM)	thiamine (2 mM)	glutamic acid (5 mM)	slight beefy, browned, grassy,	
glucose (10 mM)	ribose (10 mM)	cysteine (10 mM)	thiamine (2 mM)	glutamic acid (5 mM)	IMP (2 mM)	bacon, very umami, savory, brothy, slight beef
glucose (10 mM)		cysteine (10 mM)	thiamine (2 mM)	glutamic acid (5 mM)		beef jerky, bloody, meaty, brothy
glucose (10 mM)		cysteine (10 mM)	thiamine (2 mM)	glutamic acid (5 mM)	lactic acid (1 mM)	savory, beefy, bloody, meaty, savory, gravy
glucose (10 mM)		cysteine (10 mM)	thiamine (2 mM)	glutamic acid (5 mM)	lysine (5 mM)	roast beef
glucose (10 mM)		cysteine (10 mM)	thiamine (2 mM)	glutamic acid (5 mM)	alanine (5 mM)	boiled beef, sweet
glucose (10 mM)		cysteine (10 mM)	thiamine (2 mM)	glutamic acid (5 mM)	I + G (2 mM)	beefy with a sulfury note
glucose (10 mM)		cysteine (10 mM)		I + G (2 mM)	I + G (2 mM)	sweet, malty, umami, meaty
glucose (10 mM)		cysteine (10 mM)		I + G (2 mM)		savory, roast beef, grassy
glucose (10 mM)			glutamic acid (5 mM)			umami, savory, meaty, sweaty, fermented

Example 4: Type of Sugar Modulates Flavor Compounds Created in the Presence of Hemeprotein

The addition of different sugars to flavor reaction mixtures containing a hemeprotein and one or more flavor precursor compounds resulted in distinct differences in the flavor compounds generated and the overall flavor profile. LegH heme protein at 1% pre-cooked w/w was mixed with cysteine (10 mM) and glucose (20 mM) at pH 6 in phosphate buffer to form a flavor reaction mixture and heated to 150 C for 3 minutes; this reaction created flavor compounds known to be present in meat; see Table 8. Similarly, a flavor reaction mixture made when LegH heme protein at 1% was mixed with cysteine (10 mM) and ribose (20 mM) at pH 6 and heated to 150 C for 3 minutes created flavor compounds known to be in meat; see Table 8.

The characteristic flavor and fragrance components were mostly produced during the cooking process when the flavor precursor molecules reacted with the heme-protein. Gas chromatography—mass spectrometry (GCMS) is a method that combines the features of gas-liquid chromatography and mass spectrometry to separate and identify different substances within a test sample. Samples were evaluated by GCMS to identify the flavor compounds generated after heating and also evaluated for their sensory profiles. Volatile chemicals were isolated from the head space around the flavor reactions. The profile of the volatile chemicals in the headspace around the flavor reaction mixtures is shown in Table 8. In particular, the use of ribose created some additional compounds as compared to glucose, as shown in Table 8.

Notably, the control mixtures of cysteine with ribose or glucose heated in the absence of the LegH heme-protein did not generate the same set of flavor compounds. The flavor reaction mixtures containing LegH also were evaluated by a blinded trained sensory panel, which described the samples with ribose as having beefy, savory, brothy, and gravy-like notes, and the samples with glucose as savory, bloody, metallic, raw meat, and bouillon-like.

TABLE 8

Compounds created	Flavor compounds generated with cysteine, LegH, and either glucose or ribose in the flavor reaction mixture.	
	LegH 1%	LegH 1%
benzaldehyde	X	X
2-butanol	X	X
dimethyl trisulfide	X	X
2-pentyl-furan	X	X
2-methyl-propanal	X	X
thiazole	X	X
butyrolactone	X	X
2-acetylthiazole	X	X
pentanal	X	X
3-methyl-butanal	X	X
methyl-thiirane	X	X
nonanal	X	X
heptanal	X	X
2,3-butanedione	X	X
1,3,5-cycloheptatriene	X	X
propyl-cyclopropane	X	X
2-hexyl-furan	X	X
butanal	X	X
2-methyl-butanal	X	X
2-ethyl-furan		X
2-octanone	X	X
propanal	X	X
trichloromethane	X	
2-methyl-furan	X	X
furan	X	X
pyrazine	X	X
thiophene	X	X
1,3-dimethyl-benzene	X	X
octane		X
octanal	X	X
thiazole	X	X
2-pentanone		X
furfural	X	X
2-nonanone	X	X
(Z)-2-heptenal	X	X
(E)-2-heptenal	X	X
1-octene	X	X
formic acid, heptyl ester	X	X
2-pentyl-thiophene		X

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TABLE 8-continued

Compounds created	cysteine (10 mM), glucose (20 mM)	cysteine (10 mM), ribose (20 mM)
1-octen-3-one	X	X
3-pentyl-furan	X	X
2-propenal		X
(E)-2-tridecen-1-ol		X
benzene		X
(E)-4-octene		X
1-penten-3-one		X
4-penten-2-one	X	X
2-methyl-thiazole		X
methyl-pyrazine		X
trans-2-(2-pentenyl)furan		X
3-ethylcyclopentanone		X
pyrrole	X	X
2-thiophenecarboxaldehyde		X
3-thiophenecarboxaldehyde		X

Example 5: Heme-Protein in the Presence of Thiamine Affects the Production of Certain Flavor Compounds

The addition of thiamine in a flavor reaction mixtures with a heme protein and other flavor precursors affected the formation of 5-Thiazoleethanol, 4-methyl-furan, 3,3'-dithiobis[2-methyl-thiazole], and 4-methylthiazole. These compounds are known to be present in meat and have beefy, meaty taste notes.

Flavor reaction mixtures at pH 6 containing LegH (1%), cysteine (10 mM), thiamine (1 mM), either glucose or ribose (20 mM), and with or without glutamic acid (10 mM) were prepared and subsequently heated to 150 C for 3 minutes. These flavor reaction samples then were evaluated by GCMS for the flavor compounds generated and evaluated by a trained panel for their sensory profiles. Volatile chemicals were isolated from the head space around the flavor reactions. GCMS showed 4-methyl-5-thiazoleethanol, 3,3'-dithiobis[2-methyl]-furan, and 4-methylthiazole compounds were created by a mixture of LegH with thiamine, a sugar (either glucose or ribose), and cysteine. The same flavor reaction mixtures without thiamine did not generate these compounds; additionally these compounds were not generated when heme-proteins were not present in the flavor reaction mixtures.

The flavor reaction samples also were evaluated by a blinded trained sensory panel, which described the samples with the addition of thiamine as more complex in taste and more beefy, meaty, and savory.

Example 6: Heme-Proteins with Nucleotides Controls Particular Flavor Compound Production

The addition of inosine monophosphate and guanosine monophosphate in mixes with heme protein and other precursors controlled the formation of flavor compounds (E)-4-octene, 2-ethyl-furan, 2-pantanone, 2,3-butanedione, 2-methyl-thiazole, methyl-pyrazine, tridecane, (E)-2-octenal, 2-thiophenecarboxaldehyde, and 3-thiophenecarboxaldehyde. These compounds are known to be present in meat and have a beefy, meaty, buttery, and or savory flavor notes.

Reactions containing heme protein at 1% (LegH) with cysteine (10 mM), and glucose (20 mM), 1 mM IMP and 1 mM GMP, at pH 6.0 were prepared and heated to 150 C for

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3 minutes. Characteristic flavor and fragrance components were mostly produced during the cooking process where precursors reacting heme-protein. These samples were evaluated by GCMS for the flavor compounds generated and evaluated for the sensory experience. Volatile chemicals were isolated from the head space around the flavor reaction and identified using GCMS, creating a profile of the volatile chemicals in the headspace around the flavor reaction mixture. GCMS showed 4-octene, 2-ethyl furan, 2-pantanone, 2,3-butanedione, 2-methyl-thiazole, methyl-pyrazine, tridecane, 2-octenal, 2-thiophenecarboxaldehyde, 3-thiophenecarboxaldehyde compounds were created by a mixture of hemeprotein LegH with IMP, GMP, glucose, and cysteine. The same samples without IMP and GMP did not generate these compounds, additionally these compounds were also not created when heme-proteins were not present, just precursor molecules. Sensory evaluation by blinded trained panelist found the samples with the addition of inosine and guanosine as described as having more complexity in taste and more beefy, meaty, brothy and savory. FIG. 2 shows the abundance of the novel flavor compounds created with heme protein at 1% was mixed in a reaction at pH 6, with cysteine (10 mM), and glucose (20 mM), IMP (1 mM) and GMP (1 mM), and detected by solid phase microextraction (SPME) and then detected by GCMS.

Example 7: Flavor Generation with the Addition of a Particular Organic Acid

The addition of lactic acid in mixes with heme protein, ribose, and cysteine controlled the formation of the flavor compounds nonanal, thiazole, 2-acetylthiazole, and 8-methyl-1-undecene. These compounds are known to be present in meat.

Reactions containing heme protein at 1%, cysteine (10 mM), and ribose (20 mM), and lactic acid (1 mM), pH 6.0, were prepared and heated to 150 C for 3 minutes. Characteristic flavor and fragrance components were mostly produced during the cooking process where precursors reacting heme-protein. These samples were evaluated by GCMS for the flavor compounds generated and evaluated for the sensory experience. Volatile chemicals were isolated from the head space around the flavor reaction and identified using GCMS, creating a profile of the generated compounds. Nonanal, thiazole, 2-acetylthiazole, and 8-methyl-1-undecene compounds were created by a mixture of LegH with lactic acid, ribose, and cysteine. The same samples without lactic acid did not generate these compounds, additionally these compounds were not created in the absence of heme-proteins.

Sensory evaluation by blinded trained panelist found the samples with the addition of lactic acid as described as beefy, savory, browned, bready, and having malty notes. The sample with everything but lactic acid rated lower in browned, bready and malty notes.

Example 8: Flavor Generated with the Addition of a Particular Amino Acid

The addition of lysine in mixes with heme protein ribose, and cysteine controlled the formation of flavor compounds dimethyl trisulfide, nonanal, 2-pentyl-thiophene, furfural, 2-nonenal, 1-octanol, 2-nonenal, thiazole, 2-acetylthiazole, phenylacetaldehyde, 2-acetylthiazole. These compounds are known to be present in meat and some have a beefy, meaty, and or savory flavor.

Reactions containing heme protein at 1%, cysteine (10 mM), and ribose (20 mM), and lysine (1 mM), at pH 6.0, were prepared and heated to 150 C for 3 minutes. These samples were evaluated by GCMS for the flavor compounds generated and evaluated for the sensory experience. Characteristic flavor and fragrance components were mostly produced during the cooking process where precursors could react with the heme-protein. These samples were evaluated by GCMS for the flavor compounds generated and evaluated for the sensory experience. Volatile chemicals were isolated from the head space around the flavor reaction. Dimethyl trisulfide, nonanal, 2-pentyl-thiophene, furfural, 2-nonenal, 1-octanol, 2-nonenal, thiazole, 2-acetylthiazole, phenylacet-aldehyde, 2-acetylthiazole compounds were created by a mixture of LegH with lactic acid, ribose, and cysteine. The same samples without lactic acid did not generate these compounds, additionally these compounds were not created when heme-proteins were not present, just precursor molecules. Sensory evaluation by blinded trained panelist found the samples with the addition of lysine as described as roast beefy, savory, and browned. The addition of lysine increased the roasted browned notes.

**Example 9—Flavor Compound Production by Different Heme-Proteins**

The addition of different types of heme-proteins (LegH, Barley, *B. myoglobin*, or *A. aeolicus*) in flavor reaction mixtures containing one or more flavor precursor compounds results in many of the same key meat flavors, including but not limited to 2-pentyl-furan, 2,3-Butanedione, Thiophene, 2-methyl-thiazole, Pyrazine, Furan, Pyrrole, 2-methyl-furan and distinct differences in the flavor compounds, including but not limited to 2-pentyl-thiophene, Nonanal, 2-Nonanone, and 1-Octen-3-one. These differences in flavor compounds can change the overall taste profile. The different types of heme-protein were LegH, Barley, *B. myoglobin*, or *A. aeolicus* used at 1% w/w in a reaction mixed with cysteine (10 mM) and ribose (10 mM) at pH 6. The pre-reaction mixture was heated to 150 C for 3 minutes; this reaction created flavor compounds known to be present in meat; see Table 9. The characteristic flavor and fragrance components are mostly produced during the cooking process where the flavor precursor molecules react with the heme-protein. Samples were evaluated by GCMS to identify the flavor compounds generated after heating and also evaluated for their sensory profiles. Volatile chemicals were isolated from the head space around the flavor reactions. Table 9 shows the similarity and differences in volatile flavor compounds created by the different types of heme-proteins.

TABLE 9

Flavor compounds created by different heme-protein when heated with ribose and cysteine.

Name	LegH	Barley	<i>B. myoglobin</i>	<i>A. aeolicus</i>
Furan	x	x	x	x
Thiazole	x	x	x	x
benzaldehyde	x	x	x	x
2-acetylthiazole	x	x	x	x
2-methyl-propanal	x	x	x	x
furfural	x	x	x	x
2,3-butanedione	x	x	x	x
2-pentyl-furan	x	x	x	x
2-pentanone	x	x	x	x
pyrazine	x	x	x	x

TABLE 9-continued

Flavor compounds created by different heme-protein when heated with ribose and cysteine.					
	Name	LegH	Barley	<i>B. myoglobin</i>	<i>A. aeolicus</i>
10	dimethyl trisulfide	x	x	x	x
	3-methyl-butanal	x	x		x
	2-methyl-thiazole	x	x	x	x
	pentanal	x	x	x	x
	1,3,5-cycloheptatriene	x	x	x	x
	methacrolein	x	x	x	x
	heptanal	x	x	x	x
	2-methyl-butanal	x	x		x
	isothiazole	x	x	x	x
	thiophene	x	x	x	x
15	propanal	x	x	x	x
	2-heptenal	x	x	x	x
	methyl-pyrazine	x	x	x	x
	1-octene	x		x	x
	butanal	x	x	x	x
	2-acetyl-propen-2-ol	x	x	x	x
	pyrrole	x	x	x	x
	2-methyl-furan	x	x	x	x
	nonanal		x	x	x
	2-propenal		x	x	x
20	2-decenal		x	x	x
	2-nonanone	x			x
	2-octanone		x	x	x
	2-tridecen-1-ol			x	x
	2-octanone			x	
	30	2-octenal		x	x
	4-methyl-2-heptanone		x	x	x
	octanal			x	x
	2-undecenal				x
	butyrolactone				x
35	1-octen-3-one				x
	3-methylheptyl acetate				x
	2-pentyl-thiophene				x

**Example 10—Generation of Meat Flavors from Different Lipids**

Several different samples including oils (canola oil or coconut oil), free fatty acids (FFA) (linoleic acid (C18:2), oleic acid (C18:1), stearic acid (C18:0), or myristic acid (C14:0)) and phospholipids (PL) (beef heart polar lipids extract, Biolipon95 (from Perimond), or NatCholinePC40 (from Perimond)) were tested for their ability to produce beefy flavor in the absence and in the presents of other precursors. Oils, FFAs, and PLs were added to 50 mM potassium phosphate buffer (PPB) pH 6.0 or a Maillard reaction mix (MRM) containing 50 mM potassium phosphate pH 6.0, 5 mM Cysteine, 10 mM Glucose, 0.1 mM Thiamine, and 0.1% (w/v) LegHemoglobin. Lipids in combination with MRM were designed to capture the cross reactions of lipid degradation and Maillard reaction productions while lipids in phosphate buffer functioned as a lipid control. The oils were added at 3% of the total 1 mL volume of solution while FFAs and PLs were added at 1% of the total 1 mL volumes. All samples were cooked at 150° C. for 3 mins, cooled to 50° C. and then analyzed using GCMS (SPME fiber sampling of headspace). After all samples were analyzed by GCMS the caps were removed and samples were smelled by a trained flavor scientist and aromas recorded.

TABLE 10

Legend showing components of each sample		
Sample Name	Solution	Additives
MRM_None	Maillard Reaction Mix	None
MRM_Linoelic Acid	Maillard Reaction Mix	1% linoleic acid
MRM_Oleic Acid	Maillard Reaction Mix	1% oleic acid
MRM_C14	Maillard Reaction Mix	1% C14:0 free fatty acid
MRM_C18	Maillard Reaction Mix	1% C18:0 free fatty acid
MRM_Canola	Maillard Reaction Mix	3% Canola Oil
MRM_Coconut	Maillard Reaction Mix	3% Coconut Oil
MRM_BeefHeart	Maillard Reaction Mix	1% Beef Heart Polar Lipids Extract
MRM_Biolipon95	Maillard Reaction Mix	1% Biolipon95 (emulsifier)
MRM_NatCholinePC40	Maillard Reaction Mix	1% NatCholinePC40 (emulsifier)
KPhos6_Linoelic Acid	PPB, pH 6	1% linoleic acid
KPhos6_Oleic Acid	PPB, pH 6	1% oleic acid
KPhos6_C14	PPB, pH 6	1% C14:0 free fatty acid
KPhos6_C18	PPB, pH 6	1% C18:0 free fatty acid
KPhos6_Canola	PPB pH 6	3% Canola Oil
KPhos6_Coconut	PPB, pH 6	3% Coconut Oil
KPhos6_BeefHeart	PPB, pH 6	1% Beef Heart Polar Lipids Extract
KPhos6_Biolipon95	PPB, pH 6	1% Biolipon95 (emulsifier)
KPhos6_NatCholinePC40	PPB, pH 6	1% NatCholinePC40 (emulsifier)

Table 11 contains the aroma descriptions and Table 12 contains the GCMS data from the most interesting samples analyzed. Many of the lipids introduced a “fatty” aroma to MRM that was otherwise absent. The combinations of Linoleic Acid or NatCholinePC40 in MRM produced the greatest abundance of fatty compounds suggesting that these lipids may improve the flavor perception of beef tallow. Linoleic Acid and NatCholinePC40 also showed high abun-

dance of earthy-mushroom aromas. The addition of lipids to MRM significantly increased the abundance of “nutty & roasted” aromas. Less desirable “green” aroma compounds were most prominent in samples with unsaturated free fatty acids (linoleic acid or oleic acid) or phospholipids. In general, the addition of lipids significantly increased the number of target beef compounds made.

TABLE 11

Aroma descriptions of each sample after it was cooked.		
	Sample Names	Aroma Descriptions
10	MRM_Only	brothy, malty, beef stew
15	KPhos6_BeefHeart	fatty, creamy, beef tallow, slight sweet, slight roasted nutty
15	MRM_BeefHeart	fatty, beef tallow, old meat, mushroom
15	KPhos6_Biolipon95	fatty, fresh
15	MRM_Biolipon95	fatty, brothy, hay, malty green
15	KPhos6_NatCholinePC40	light fatty, fresh
15	MRM_NatCholinePC40	fatty, beef tallow, brothy
20	K-Phos6_C14	light/faint plastic/waxy
20	MRM_C14	brothy, beefy, minty, fresh
20	K-Phos6_C18	light/faint plastic/waxy
20	MRM_C18	beefy with cucumber &/or pepper aroma
20	K-Phos6_Canola	fresh, cucumber
20	MRM_Canola	fatty, brothy, oil, roasted nuts
25	K-Phos6_Coconut	nothing
25	MRM_Coconut	brothy, beefy, slight fatty, crackers
25	K-Phos6_Oleic Acid	fresh, cucumber, camphorous/minty-like
25	MRM_OleicAcid	herbal, plastic, slight cheesy, brothy
25	K-Phos6_Linoelic Acid	light plastic
35	MRM_Linoelic Acid	fatty, light waxy, brothy, herbal

TABLE 12

Compounds in Beef	List of aromatic compounds found in Beef by GCMS and a chart showing which were detected in each lipid plus MRM sample.			
	MRM only	MRM_BeefHeart	MRM_NatCholinePC40	MRM_Linoelic acid
(s)-isopropyl lactate	N	N	N	N
1-ethyl-5-methylcyclopentene	Y	Y	Y	Y
1-heptanol	N	Y	N	N
1-hepten-3-ol	N	Y	Y	Y
1-heptene	N	Y	Y	Y
2-methyl-1-heptene	N	N	N	N
1-hexanol	N	Y	Y	Y
2-ethyl-1-hexanol	N	N	N	N
1-nonanol	N	N	Y	N
1-nonene	N	Y	Y	N
1-octanol	N	Y	Y	N
1-octen-3-ol	N	Y	Y	Y
1-octen-3-one	Y	Y	Y	Y
1-octene	N	N	N	N
1-pentanol	N	Y	Y	Y
1-penten-3-ol	N	Y	Y	N
1-propanol	N	N	N	N
8-methyl-1-undecene	N	Y	Y	Y
1,3-hexadiene	N	N	N	Y
3-ethyl-2-methyl-1,3-hexadiene	N	Y	Y	Y
1,3-octadiene	Y	N	N	Y
1,3,5-cycloheptatriene	N	N	N	N
2,3-dihydro-5,6-dimethyl-	N	N	N	N
1,4-dioxin				
1,7-octadien-3-ol	N	Y	N	N
1h-pyrrole-2-carboxaldehyde	N	N	N	N

TABLE 12-continued

List of aromatic compounds found in Beef by GCMS and a chart showing which were detected in each lipid plus MRM sample.

Compounds in Beef	MRM only	MRM_BeefHeart	MRM_NatCholinePC40	MRM_Linoleic acid
2-methyl-1H-pyrrole	N	N	N	N
2-acetyl-2-thiazoline	Y	N	N	N
2-acetylthiazole	Y	Y	Y	Y
2-butanone	N	Y	Y	Y
2-butenal	N	Y	Y	Y
2-ethyl-2-butenal	N	N	N	Y
3-methyl-2-butenal	N	N	Y	Y
3-methyl-2-cyclohexen-1-one	N	N	N	N
2-decanone	Y	Y	Y	N
(E)-2-decenal	N	N	N	N
(Z)-2-decenal	Y	Y	Y	Y
2-furanmethanol	N	N	N	N
2-heptanone	Y	Y	Y	Y
6-methyl-2-heptanone	N	N	Y	N
(E)-2-heptenal	N	Y	Y	Y
(Z)-2-heptenal	N	N	N	Y
(E)-2-hexenal	N	Y	Y	Y
2-ethyl-2-hexenal	N	N	N	N
2-methyl-2-heptene	Y	N	N	N
2-n-heptylfuran	Y	N	N	N
2-n-octylfuran	Y	Y	Y	N
2-nonanone	N	Y	Y	N
(E)-2-nonenal	Y	Y	Y	Y
(Z)-2-nonenal	N	N	N	Y
2-octanone	Y	Y	Y	Y
(Z)-2-octen-1-ol	Y	Y	Y	Y
(E)-2-octenal	N	Y	Y	Y
2-pentanone	N	Y	Y	N
1-propoxy-2-propanol	N	N	N	N
1-(acetoxy)-2-propanone	Y	N	N	N
1-hydroxy-2-propanone	Y	N	N	N
2-propenal	N	N	N	Y
2-thiophenecarboxaldehyde	Y	Y	Y	Y
2-undecenal	N	Y	Y	Y
2,3-butanedione	N	N	N	Y
2,3-pentanedione	N	N	N	N
(E,E)-2,4-decadienal	N	Y	Y	Y
2,4-decadienal	N	N	N	Y
(E,E)-2,4-heptadienal	N	Y	Y	Y
(E,E)-2,4-nonenal	N	Y	Y	Y
2,6-dimethylpyrazine	N	N	N	N
(E,Z)-2,6-nonenal	N	N	Y	N
5-ethylidihydro-2(3H)-furanone	N	Y	Y	Y
5-methyl-2(3H)-furanone	N	N	N	N
dihydro-5-pentyl-2(3H)-furanone	N	N	Y	Y
dihydro-5-propyl-2(3H)-furanone	N	N	N	N
2(5H)-furanone	N	N	N	N
tetrahydro-6-methyl-2H-pyran-2-one	N	N	N	N
3-ethylcyclopentanone	N	Y	Y	Y
3-hexanone	N	N	N	N
3-methyl-2-thiophenecarboxaldehyde	N	N	N	N
3-octanone	Y	Y	N	Y
3-octen-2-one	N	Y	Y	Y
3-thiophenecarboxaldehyde	N	Y	Y	Y
(E,E)-3,5-octadien-2-one	N	N	Y	Y
dihydro-2-methyl-3(2H)-furanone	N	N	N	N
4-cyanocyclohexene	N	N	N	N
4-cyclopentene-1,3-dione	N	N	Y	N
4-decyne	N	Y	N	N
(Z)-4-heptenal	N	Y	Y	Y
4-methyloctanoic acid	N	N	N	N
(E)-4-octene	N	N	N	N
2,3-dihydro-3,5-dihydroxy-6-methyl-4(H)-pyran-4-one	Y	N	N	N
6-methyl-5-hepten-2-one	Y	N	N	N
acetaldehyde	N	N	N	Y
acetic acid	N	N	N	N
acetic acid ethenyl ester	Y	N	N	N

TABLE 12-continued

List of aromatic compounds found in Beef by GCMS and a chart showing which were detected in each lipid plus MRM sample.

Compounds in Beef	MRM only	MRM_BeefHeart	MRM_NatCholinePC40	MRM_Linoleic acid
acetoin	Y	N	N	N
acetone	Y	N	N	Y
acetonitrile	N	N	N	Y
benzaldehyde	Y	Y	Y	Y
4-ethyl-benzaldehyde	N	Y	Y	N
benzene	Y	N	N	N
benzoic acid, hydrazide	Y	N	N	N
butanal	Y	N	N	Y
2-methyl-butanal	N	N	N	N
3-methyl-butanal	Y	N	N	N
butanoic acid	N	N	N	N
butyrolactone	Y	Y	N	Y
caprolactam	N	N	N	N
carbon disulfide	N	N	N	Y
1-ethyl-1-methyl-cyclopentane	Y	Y	Y	Y
propyl-cyclopropane	N	N	Y	Y
decanal	N	Y	Y	N
dihydro-3-(2H)-thiophenone	N	N	N	N
Dimethyl sulfide	Y	N	N	N
dimethyl sulfone	N	N	N	N
dimethyl trisulfide	Y	Y	N	N
ethanethiol	N	N	N	N
ethanol	N	N	N	Y
1-(1(H)-pyrrol-2-yl)-ethanone	N	N	N	N
1-(2-furanyl)-ethanone	N	N	N	N
ethosuximide	Y	N	N	N
formic acid, heptyl ester	Y	Y	N	N
furan	Y	N	N	Y
2-ethyl-furan	Y	N	N	N
2-hexyl-furan	Y	N	N	Y
2-methyl-furan	N	N	N	Y
2-pentyl-furan	N	Y	Y	Y
2-propyl-furan	N	N	Y	Y
3-methyl-furan	Y	N	N	N
3-pentyl-furan	Y	Y	Y	Y
furfural	N	Y	Y	Y
heptanal	N	Y	Y	Y
heptanoic acid	N	N	N	Y
2-methyl-hex-2-yn-4-one	N	N	N	N
hexanoic acid	N	N	N	Y
hydrogen sulfide	N	N	N	N
m-aminophenylacetylene	N	N	N	N
maleic anhydride	N	N	N	N
methacrolein	N	N	N	N
methanethiol	N	N	N	N
methyl ethanoate	N	N	N	N
methyl isobutyl ketone	Y	N	N	N
n-caproic acid vinyl ester	N	Y	Y	N
nonanal	N	Y	Y	Y
3-methyl-nonane	Y	N	N	N
nonanoic acid	Y	N	N	N
octanal	N	Y	Y	Y
octane	N	N	N	Y
octanoic acid	N	N	N	Y
oxalic acid, isobutyl pentyl ester	Y	N	N	N
p-cresol	N	N	N	N
pentanal	N	N	N	Y
pentanoic acid	Y	N	N	Y
4-ethyl-phenol	N	Y	Y	N
phenylacetaldehyde	Y	Y	Y	Y
(p-hydroxyphenyl)-phosphonic acid	Y	N	N	N
propanal	N	N	N	Y
2-methyl-propanal	N	N	N	N
propanoic acid	N	N	N	N
2-methyl-propanoic acid	Y	N	N	N
propanoic acid, ethenyl ester	N	N	N	N
pyrazine	N	Y	N	Y
2-ethyl-5-methyl-pyrazine	N	N	N	N
2-ethyl-6-methyl-pyrazine	N	N	N	N
2,3-dimethyl-pyrazine	N	N	N	N

TABLE 12-continued

Compounds in Beef	MRM only	MRM_BeefHeart	MRM_NatCholinePC40	MRM_Linoleic acid
2,5-dimethyl-pyrazine	N	N	N	N
3-ethyl-2,5-dimethyl-pyrazine	Y	N	N	N
ethyl-pyrazine	N	N	N	N
methyl-pyrazine	N	N	N	N
trimethyl-pyrazine	Y	N	N	N
pyridine	Y	N	Y	N
pyrrole	Y	Y	Y	Y
styrene	Y	N	Y	N
thiazole	Y	Y	Y	Y
methyl-thiirane	N	N	N	N
thiophene	N	N	N	Y
2-hexyl-thiophene	Y	N	Y	N
2-pentyl-thiophene	N	Y	N	N
trans-2-(2-pentenyl)furan	N	Y	Y	N
trans-3 --nonen-2-one	N	Y	Y	Y
undecanoic acid	N	N	N	N
Total # of Compounds Detected:	54	63	66	76

In samples having fatty or creamy aromas, 2,4-decadienal, (E,E)-2,4-nonadienal, (E,E)-2,4-heptadienal, and/or (E,E)-2,4-decadienal were detected in the KPhos6\_BeefHeart, MRM\_BeefHeart, MRM\_BioLipon95, MRM\_NatCholinePC40, Kphos6\_Canola, MRM\_Canola, KPhos6\_Oleic Acid, KPhos6\_Linoleic acid and MRM\_Linoleic acid samples. For (E,E)-2,4-decadienal, the strongest signal intensity was in the MRM\_NatCholinePC40 sample, followed by the MRM\_Linoleic acid, KPhos6\_Linoleic acid, MRM\_BeefHeart, MRM\_BioLipon95, KPhos6\_BeefHeart, MRM\_Oleic Acid, and KPhos6\_Oleic Acid samples. For (E,E)-2,4-heptadienal, the strongest signal intensity was in the MRM\_NatCholinePC40 sample followed by the MRM\_Canola sample. (E,E)-2,4-heptadienal also was detected in the MRM\_BioLipon95, MRM\_BeefHeart, and MRM\_Linoleic acid samples. For (E,E)-2,4-nonadienal, the strongest signal intensity was in the MRM\_Canola and MRM\_Linoleic acid samples. (E,E)-2,4-nonadienal also was detected in the Kphos6\_Canola, MRM\_NatCholinePC40, MRM\_BioLipon95, MRM\_BeefHeart, and KPhos6\_Linoleic acid samples. For 2,4-decadienal, the strongest signal intensity was in the MRM\_Linoleic acid sample. 2,4-decadienal also was detected in KPhos6\_Linoleic acid, MRM\_Canola, and KPhos6\_Oleic Acid samples.

In samples having earthy or mushroom aromas, 3-octen-2-one, 1-octen-3-one, 3-octanone, and/or 1-octen-3-ol were detected in the KPhos6 BeefHeart, MRM\_BeefHeart, Kphos\_BioLipon95, MRM\_BioLipon95, Kphos\_NatCholinePC40, MRM\_NatCholinePC40, MRM\_Canola, KPhos6\_Oleic Acid, MRM\_Oleic Acid, KPhos6\_Linoleic acid, and MRM\_Linoleic acid samples. For 1-octen-3-ol, the strongest signal intensity was in the MRM\_Linoleic acid sample, followed by MRM\_NatCholinePC40, KPhos6\_Linoleic acid, MRM\_BeefHeart, KPhos6 BeefHeart, MRM\_Canola, MRM\_BioLipon95, KPhos6\_Oleic Acid, and MRM\_Oleic Acid samples. 3-octanone was detected in the MRM\_Oleic Acid, KPhos6\_Linoleic acid, and MRM\_Linoleic acid samples. For 1-octen-3-one, the strongest signal intensity was in the MRM\_Linoleic acid and MRM\_BeefHeart samples, followed by KPhos6\_Linoleic acid, MRM\_NatCholinePC40, KPhos6\_BeefHeart, MRM\_

<sup>25</sup> BioLipon95, MRM\_Oleic Acid, and KPhos6\_Oleic Acid samples. For 3-octen-2-one, the strongest signal intensity was in the KPhos6\_Linoleic acid sample, followed by MRM\_Linoleic acid, MRM\_NatCholinePC40, KPhos6 BeefHeart, KPhos6\_Oleic Acid, MRM\_Oleic Acid, MRM\_BeefHeart, MRM\_BioLipon95, MRM\_Canola, Kphos\_BioLipon95, and Kphos\_NatCholinePC40. Pyrazine was detected in the MRM\_Coconut, MRM\_C18, MRM\_C14, and MRM\_BioLipon95 samples.

<sup>35</sup> In samples having a nutty and roasted aroma, thiazole and 2-acetylthiazole were the most abundant compounds detected, along with pyrazine, methyl pyrazine, trimethyl pyrazine, and 3-ethyl-2,5-dimethylpyrazine. 2-acetylthiazole was detected in all samples with MRM\_and most abundant in samples with MRM\_Beefheat, MRM\_biolipon95, MRM\_Canola, and MRM\_coconut. Thiazole was created in samples with MRM-Coconut, MRM\_BeefHeat, MRM\_Biolipon95, MRM\_C14, MRM\_C18, MRM\_Canola, MRM\_Oleic acid and MRM\_Linoleic acid and MRM\_NatCholinePC40. Pyrazine was present in the largest amount in samples with MRM-Coconut, followed by samples MRM\_BeefHeat, MRM\_Biolipon95, MRM\_C14, MRM\_C18, MRM\_Canola having roughly equal amount, MRM\_Oleic acid and MRM\_Linoleic acid sample had even less. Methyl-pyrazine was present in MRM\_Biolipon95 and MRM\_Coconut. 3-ethyl-2,5-dimethyl-pyrazine and trimethyl-pyrazine, were present only without phospholipids in the MRM.

<sup>55</sup> In samples having green, vegetable, or grass aromas, 1-heptanol, 1-hepten-3-ol, 1-hexanol, (E)-2-heptenal, (Z)-2-heptenal, (E)-2-hexenal, 2-pentyl-furan, and/or heptanal were detected in the KPhos6 BeefHeart, MRM\_BeefHeart, Kphos\_BioLipon95, MRM\_BioLipon95, Kphos\_NatCholinePC40, MRM\_NatCholinePC40, Kphos\_C14, MRM\_C14, Kphos\_C18, MRM\_C18, MRM\_Canola, MRM\_Coconut, KPhos6\_Oleic Acid, MRM\_Oleic Acid, KPhos6\_Linoleic acid, and MRM\_Linoleic acid samples. For 2-pentyl-furan, the strongest signal intensity was in the KPhos6 BeefHeart sample, followed by the KPhos6\_Linoleic acid, MRM\_BioLipon95, MRM\_Linoleic acid, MRM\_BeefHeart, MRM\_Oleic Acid, MRM\_NatCholinePC40, MRM\_Canola, KPhos6\_Oleic Acid, and Kphos\_

NatCholinePC40 samples. For (E)-2-heptenal, the strongest signal intensity was in the MRM\_BeefHeart, MRM\_Canola, MRM\_Oleic Acid, and KPhos6\_Linoleic acid samples, followed by the KPhos6\_Oleic Acid, MRM\_BioLipon95, KPhos6\_BeefHeart, MRM\_Linoleic acid, MRM\_NatCholinePC40, Kphos\_BioLipon95, and Kphos\_NatCholinePC40 samples. For (Z)-2-heptenal, the strongest signal intensity was in the MRM\_Linoleic acid sample. MRM\_Linoleic acid also was detected in the KPhos6\_Linoleic acid sample. For heptanal, the strongest signal intensity was in the MRM\_Oleic Acid sample, followed by the KPhos6\_Oleic Acid, MRM\_C14, MRM\_C18, MRM\_Canola, MRM\_BeefHeart, MRM\_NatCholinePC40, MRM\_Linoleic acid, and KPhos6 BeefHeart samples. For, (E)-2-hexenal, the strongest signal intensity was in the MRM\_Linoleic acid sample, followed by the MRM\_NatCholinePC40, KPhos6\_Linoleic acid, and MRM\_Oleic Acid samples.

Example 11—Creation of Beefy Flavors Using Complex Precursor Mixtures

A formulation was prepared (the “magic mix,” see Table 13 containing the estimated concentrations of amino acids, sugars, and other small molecules in beef based on their values reported in literature. The magic mix was tested for its ability to produce beefy flavors in the presence of LegHemoglobin (LegH). The magic mix and 1% w/v LegH were added to the meat replica, pH 6.0 (see Table 4) and baked in a convection oven for 7 minutes at 160° C. A control sample was prepared by adding 1% w/v LegH to the meat replica, pH 6.0 and baking in a convection oven for 7 minutes at 160° C.

The meat replica sample containing only LegH, was compared to the meat replica sample containing the magic mix and LegH by a sensory panel and GCMS analysis. Five tasters rated the flavored meat replicas for beefiness, bitterness, and levels of savory flavors, and off flavors. Each property was rated on a 7 point scale in which 7 was the highest amount of the specified property (e.g., a standard 80:20 ground beef would be rated 7 on the beefy scale). The Magic Mix flavor was rated one point higher in beefy character than the LegH only sample (FIG. 1).

To determine which chemical products were produced upon heating, a solution of Magic Mix was prepared with 1% w/v LegH at pH 6.0. The samples were cooked with shaking at 150° C. for three minutes, then Solid Phase Micro Extraction (SPME) was performed for twelve minutes at 50° C. to extract the volatile compounds above the headspace of the reaction. A search algorithm was used to analyze the retention time and mass fingerprint information of the volatile compounds and assign chemical names to peaks. Table 14 shows the compounds identified in both the Magic Mix+LegH (MM, average of two samples) and in the LegH alone in buffer (LegH, average of five samples) samples. The compounds in Table 14 are listed in order of the retention time (R.T., in seconds), and are designated as having a zero peak area (0), or a small (S), medium (M), or large (L) average peak area. Hundreds of compounds were identified between the samples, many of which are characteristic of beefy aroma, including but not limited to 1,3-bis(1,1-dimethyl-ethyl)-benzene, 2-methyl 3-furanthiol, and Bis(2-methyl-4,5-dihydro-3-furyl)disulfide, which increased in the samples containing the Magic Mix and LegH.

TABLE 13

Chemical entities added to the Magic Mix		
	Chemical entity	mM
5	Alanine	5.6
	Arginine	0.6
	Asparagine	0.8
	Aspartate	0.8
	Cysteine	0.8
10	Glutamic acid	3.4
	Glutamine	0.7
	Glycine	1.3
	Histidine	0.6
	Isoleucine	0.8
	Leucine	0.8
15	Lysine	0.7
	Methionine	0.7
	Phenylalanine	0.6
	Proline	0.9
	Threonine	0.8
20	Tryptophan	0.5
	Tyrosine	0.6
	Valine	0.9
	glucose	5.6
	Ribose	6.7
	Maltodextrin	5.0
25	Thiamine	0.5
	GMP	0.24
	IMP	0.6
	Lactic acid	1.0
	creatine	1.0
30	NaCl	10
	KCl	10
	Kphos pH 6.0	10

TABLE 14

Compounds identified with GC-MS analysis in samples with MM and LegH, or LegH alone (average of five samples)			
R.T.(s)	Name	MM with LegH	LegH alone
35	248 acetaldehyde	L	S
	256.3 carbon disulfide	L	S
	264.3 dimethyl sulfide	S	0
40	265 oxalic acid, isobutyl pentyl ester	M	0
	268.1 2,3,4-trimethyl-pentane	M	0
	269.2 methanethiol	S	0
45	283.4 propanal	M	0
	285.4 octane	M	0
	287.1 furan	M	0
	295.3 2-methyl-propanal	L	S
	297.6 acetone	L	S
50	319.3 2-propenal	M	S
	338.1 2-methyl-furan	M	S
	342.1 butanal	L	S
55	344.2 2,4-dimethyl-1-heptene	M	0
	346.3 methacrolein	M	0
	357.4 methyl-thiirane	L	0
	360.2 3-methyl-furan	S	0
60	363.7 butanone	L	S
	368.9 2,3-dihydro-5-methyl-furan	M	S
	376.4 2-methyl-butanal	L	M
	381.1 3-methyl-butanal	L	M
	390.6 isopropyl alcohol	0	S
	399.6 ethanol	L	M
65	406.2 2-propenoic acid, methyl ester	M	0
	408.2 benzene	S	0
	414.4 methyl vinyl ketone	M	0
	416.4 2,2,4,6,6-pentamethyl-heptane	M	0
	422.6 2-ethyl-furan	S	0
	438.4 2-ethylacrolein	M	0
	449.9 2-pentanone	S	0
	453.2 pentanal/2,3-butanedione	L	0
	453.8 2,3-butanedione	L	M

TABLE 14-continued

Compounds identified with GC-MS analysis in samples with MM and LegH, or LegH alone (average of five samples)			
R.T.(s)	Name	MM with LegH	LegH alone
472.8	4,7-dimethyl-undecane	M	S
485.9	2-methyl-pentanal	M	0
492.6	2-methyl-1-penten-1-one	S	0
496.6	(E)-3-penten-2-one	M	0
508.6	1-penten-3-one	M	0
510.6	trichloromethane	M	M
520.4	p-dithiane-2,5-diol	M	0
525.5	3-methyl-pentanal	M	0
535.1	(E)-5-decene	M	0
536.5	toluene	M	S
537.9	2-butenal	M	S
543.8	4-penten-2-one	M	0
550.8	methyl thiolacetate	M	0
683.7	p-xylene	S	0
727.4	dimethyl selenone	M	0
738.3	methyl isopropyl disulphide	M	0
755	2-heptanone	M	0
758.7	heptanal	L	0
781.9	1,3-diisopropoxy-1,3-dimethyl-1,3-disilacyclobutane	S	M
789.4	3-methyl-2-butenal	M	0
793.4	4-methyl-2-heptanone	M	0
810.4	pyrazine	M	0
818.8	isothiazole	S	0
827.1	acetyl valeryl	M	0
831.8	2-pentyl-furan	L	0
851	2-methyl-thiazole	S	0
853.3	isothiocyanato-methane	S	0
870.9	thiazole	L	0
879.2	styrene	M	0
890.7	1-(methylthio)-propane	M	0
895.6	methyl-pyrazine	M	0
910.5	thiocyanic acid, methyl ester	S	0
918.6	4-methylthiazole	M	0
921.4	2-octanone	M	0
923.9	2-methyl-cyclopentanone	M	0
927.9	octanal	L	S
934.3	tridecane	M	0
948.8	trans-2-(2-pentenyl)furan	S	0
961.9	1-hydroxy-2-propanone	M	0
974.5	(E)-2-heptenal	M	0
987.4	5-methyl-1-undecene	M	0
993.8	2-hexyl-furan	M	0
1007.8	7-methyl-(E)-5-undecene	M	0
1024.1	2-methyl-5-(methylthio)-furan,	S	0
1058.6	2-butyl-1-decene	M	0
1079.3	dimethyl trisulfide	L	S
1085.3	2-nonanone	M	0
1093.2	nonanal	L	M
1142.3	1,3-bis(1,1-dimethylethyl)-benzene	M	0
1149.6	(E)-2-octenal	M	0
1164.5	1-heptanol	M	0
1193.5	methional	L	0
1198.8	acetic acid	M	S
1207.2	furfural	M	0
1242.1	2-decanone	M	0
1250.8	decanal	M	0
1265.2	1-decen-3-one	M	0
1283.3	pyrrole	M	0
1292.6	5-ethenyl-4-methyl-thiazole	M	0
1294.3	benzaldehyde	L	M
1303.7	2-n-octylfuran	M	0
1305.6	(E)-2-nonenal	M	0
1341.4	1-octanol	M	0
1361.1	2-methyl-1(H)-pyrrole	S	0
1391.7	2-undecanone	M	0
1401.2	(E)-2-octen-1-ol	M	0
1448	butyrolactone	S	S
1456.3	(E)-2-decenal	M	0
1462.4	phenylacetaldehyde	L	S
1466.3	2-acetylthiazole	L	0
1471.3	acetophenone	M	S
1475.4	1-nonanol	M	0

TABLE 14-continued

Compounds identified with GC-MS analysis in samples with MM and LegH, or LegH alone (average of five samples)				
R.T.(s)	Name	MM with LegH	LegH alone	
5				
10	1487	methyl (methylthio)methyl disulfide	M	0
	1497.1	5-(2-chloroethyl)-4-methylthiazole	L	0
	1497.5	1-(ethylthio)-2-(methylthio)-buta-1,3-diene	L	S
	1512	3-thiophenecarboxaldehyde	M	0
	1518.8	2-nonen-4-one	M	0
	1531.7	2-thiophenecarboxaldehyde	S	0
	1543.9	dodecanal	M	0
	1551.6	4-ethyl-2-methyl-pyrrole	S	0
	1558.2	3-(methylthio)-propanenitrile	S	0
	1561.2	3-decen-2-one	M	0
	1613.1	bis(2-methyl-4,5-dihydro-3-furyl) disulfide	M	0
	1615.6	1,10-undecadiene	M	0
	1619.5	2-undecenal	S	0
	1668.9	2-phenylpropenal	M	0
	1692.3	(Z)-3-decen-1-ol, acetate	M	0
	1733.1	3-phenyl-furan	S	0
	1739.7	4-nitrophenyl 2-thiophenecarboxylic acid ester	S	0
15	1741.2	5-formyl-4-methylthiazole	M	0
	1749.7	pentanoic acid, 2,2,4-trimethyl-3-hydroxy-, isobutyl ester	M	0
20	1765.5	benzyl alcohol	S	0
	1774.2	pentanoic acid, 2,2,4-trimethyl-3-hydroxy-, isobutyl ester	S	0
25	1796.9	dodecanal	M	0
	1806.1	(1-ethyl-1-propenyl)-benzene	S	0
	1825.6	1-undecanol	M	S
30	1827.9	2-methyl-3-furanthiol	M	0
	1828.3	2-methyl-3-(methylthio) furan	M	0
	1836.1	4-chloro-2,6-bis(1,1-dimethylethyl)-phenol	S	0
	1844.1	phenol	S	S
	1845.3	[(methylsulfonyl)methyl]-benzene	S	0
	1850.3	(e)-2-tridecen-1-ol	M	0
35	1859.9	1-heptyl-1,2,3,4-tetrahydro-4-methyl-naphthalene	S	0
	1863.2	2,4-decadienal	S	0
	1905.1	3,3'-dithiobi[2-methyl]-furan	M	0
	1906.9	3,5-di-tert-butylbenzoic acid	S	0
	1909.6	4-ethoxy-benzoic acid, ethyl ester	S	0
	1921.5	3-(phenylmethyl)-2,5-piperazinedione	S	0
40	1944.5	9-octadecenal	M	0
	1959.7	3,5-bis(1,1-dimethylethyl)-phenol	M	S
	1968.4	4-methyl-5-thiazoleethanol	M	S
	2007.8	1,1'-(1,2-cyclobutanediyl)bis-cis-benzene	S	0
	2019.8	benzoic acid	S	S
	2026.4	4-quinoliniccarboxaldehyde	S	0
45	2027.8	m-aminophenylacetylene	M	0
50				

**Example 12—Ferrous Chlorin Catalyzes Production of Meat-Like Flavor Compounds**

Fresh green spinach (10 lb) was added to 500 mL water and finely ground in a Vitamix blender to yield 2 L of green suspension. Acetone (8 L) was added with mixing and the material was allowed to extract for 1 hour. The material was filtered through Whatman filter paper and the acetone was removed on a rotary evaporator (Buchi). To the residual green suspension (500 mL) was added 2 mL of 10 M HCl, causing the suspension to turn brown. To this was added 1 g of  $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$  in 10 mL  $\text{H}_2\text{O}$ . The solution was shaken then left at 4° C. for 16 hours. This suspension was extracted with diethyl ether (3×50 mL) to give a bright green organic phase, the combined organics were washed with saturated sodium chloride solution, dried over sodium sulfate, filtered and evaporated to leave a black paste (1.1 g). The pellet was dissolved in chloroform for fractionation.

Chlorophyll and Ferrous chlorin crude fractions were stored at -20° C. Crude extracts were fractionated by

39

reverse-phase high-pressure liquid chromatography (RP-HPLC). HPLC conditions are outlined in Table 15. Both chlorophyll and ferrous chlorophyll were eluted from the column with a peak retention time of 7.6 minutes. Eluted material was collected from 7.3-8.0 minutes. Collected fractions were pooled and stored on ice. Collected fractions were re-chromatographed and showed a single peak with retention time 7.6 minutes. The desired fractions were pooled, then 10% sunflower oil was added, methanol was removed on a rotary evaporator (Buchi).

TABLE 15

HPLC conditions for purification of chlorophyll and ferrous chlorin from crude extract.

Sample:	Chlorophyll or Fe-chlorin (~2 mg/mL in CHCl <sub>3</sub> )
System:	Agilent 1100 with Chemstation
Column:	Zorbax Bonus-RP (4.6 × 250 mm, 5 $\mu$ M)
Mobile phase:	acetonitrile, methanol, ethyl acetate (60:20:20) isocratic flow
Temperature:	30° C.
Flow Rate:	1.0 mL per minute
Injection volume:	0.05 mL

#### Preparation of Flavor Reaction Containing Ferrous Chlorin or Leghemoglobin

A solution of ferrous chlorophyll was mixed with the Magic Mix (Table 13) to a final concentration of 0.35% ferrous chlorin, 1% glycerol, 0.005% tween-20, 5% sunflower oil, 100 mM NaCl, 20 mM phosphate at pH 6. Leghemoglobin (0.35%) at pH 6 in phosphate buffer (20 mM), 100 mM NaCl, was mixed with the Magic Mix (Table 13), 1% glycerol, and 0.005% tween-20. The flavor reaction mixtures were heated to 150° C. for 3 minutes; this reaction created flavor compounds known to be present in meat, created by hemoglobin and also created by ferrous chlorin; see Table 16.

The characteristic flavor and fragrance components were mostly produced during the cooking process when the flavor precursor molecules reacted with the heme-protein or the ferrous chlorophyll. Samples were evaluated by GCMS to identify the flavor compounds generated after heating. Volatile chemicals were isolated from the headspace around the flavor reactions. The profile of the volatile chemicals in the headspace around the flavor reaction mixtures that were similar between heme-protein and ferrous chlorin are shown in Table 16. Notably, many of the compounds created by the ferrous chlorin are important in the flavor of meat.

TABLE 16

Flavor Compounds created by both Ferrous Chlorin and LegH with Magic Mix.

1-heptanol	acetone
1-hexanol	acetonitrile
1-octanol	benzaldehyde
1-octen-3-ol	butanal
1-octen-3-one	2-methyl-butanal
1-pentanol	dimethyl trisulfide
2-acetylthiazole	ethyl acetate
2-butenal	furan
3-methyl-2-butenal,	2-ethyl-furan
(Z)-2-decenal	2-hexyl furan
6-methyl-2-heptanone	2-pentyl-furan
(E)-2-heptenal	furfural
(E)-2-hexenal	heptanal
2-methyl-3-furanthiol	aminophenylacetylene
(E)-2-nonenal	methacrolein
(E)-2-octenal	methional
2-pentanone	octanal

40

TABLE 16-continued

Flavor Compounds created by both Ferrous Chlorin and LegH with Magic Mix.	
5	1-hydroxy-2-propanone
	2-thiophenecarboxaldehyde
	2-undecenal
	3-methyl-3-butene-2-one
	3-thiophenecarboxaldehyde
10	(E)-4-octene,
	methyl-pyrazine
	thiazole
	octane
	oxalic acid, diallyl ester
	2,3-butanedione
	2-methyl-propanal
	pyrazine
	2,3-dimethyl-pyrazine
	2,5-dimethyl-pyrazine

#### Example 13—Flavor Creation by Immobilized Hemin

##### Preparation of Hemin Linked CM Sepharose.

200 mg of bovine hemin (Sigma Aldrich) was loaded into a scintillation vial. A small magnetic stir bar, 800  $\mu$ L acetonitrile, 64  $\mu$ L 4-methylmorpholine, and 71 mg of N-hydroxysuccinimide were added in that order. The vial was placed in an ice bath and chilled then 118 mg of N-(3-dimethylaminopropyl)-N'-ethyl-carbodiimide hydrochloride was added with stirring, followed by 845  $\mu$ L of Jeffamine ED900. This was stirred while allowing the black mixture to warm to ambient temperature. Chloroform (10 mL) was added to the mixture followed by water (4 mL). A flashlight was used to distinguish between organic and aqueous layers since both were black and the organic layer 25 was pipetted off and concentrated to a dark black oil. The oil was dissolved in a 4:1 mixture of acetonitrile and ethanol to make an approximately 10% strength solution that was inky black in color.

2 mL of water swelled and equilibrated CM Sepharose 30 was equilibrated in a BioRad minicolumn with 3 volumes of acetonitrile. The resin was resuspended in 1 mL acetonitrile and pipetted into a scintillation vial. This was followed with 44 microliters 4-methylmorpholine, 23 mg N-hydroxysuccinimide, and 39 mg of solid N-(3-dimethylaminopropyl)-N'-ethyl-carbodiimide hydrochloride. The mixture was vortexed vigorously and then shaken for three hours. To this white solid was added 570 microliters of inky black 20% strength hemin coupled diamine. The black solid was vortexed and shaken for an hour. The slurry strongly resembled Turkish coffee. The mixture was poured into a BioRad 35 minicolumn and filtered, washed with acetonitrile until what came out no longer resembled espresso, then switched to deionized water, and finally 20 mM pH 9 sodium carbonate buffer. The black solid was washed until the effluent ran clear and then resuspended in 2 mL of buffer for storage until 40 use.

##### Flavor Reaction

The flavor reaction was created with heme protein (equine myoglobin-Sigma) at 0.35% in a phosphate buffer (20 mM) at pH 6.0 with 100 mM NaCl, this was mixed with Magic 45 Mix (Table 13). Another flavor reaction was created with Immobilized Hemin at 0.35% in a phosphate buffer (20 mM) at pH 6.0 with 100 mM NaCl, this was mixed with Magic Mix (Table 13). The flavor reaction mixtures were heated to 150° C. for 3 minutes; this reaction created flavor compounds known to be present in meat.

The characteristic flavor and fragrance components were mostly produced during the cooking process when the flavor precursor molecules reacted with the Heme-protein or the immobilized Hemin. Samples were evaluated by GCMS to 50 identify the flavor compounds generated after heating. Volatile chemicals were isolated from the headspace around the flavor reactions. As can be seen in Table 17, immobilized

hemin catalyzed production of compounds similar to those whose production was catalyzed by myoglobin free in solution. Notably, the profiles of flavor compounds, measured by GCMS, produced by cooking mixtures containing the immobilized hemin and the heme-protein, respectively, were very similar.

TABLE 17

Flavor compound	myoglobin	hemin-linker-resin
2-methyl-5-(methylthio)-thiophene	Low	
dihydro-5-propyl-2(3H)-furanone	Low	
octane	Low	
pyrrole	Low	Low
methanethiol	Low	Low
2-thiophenecarboxaldehyde	Low	Low
methyl-pyrazine	Low	Low
1-hydroxy-2-propanone	Low	Low
propanal	Low	Low
thiophene	Low	medium
pyridine	Low	Low
2-methyl-furan	Low	medium
oxalic acid, butyl propyl ester	Low	Low
pyrazine	medium	Low
oxalic acid, diallyl ester	medium	medium
2-butenal	medium	large
furfural	medium	medium
nonanal	medium	medium
2-ethyl-furan	medium	Low
ethanol	medium	very large
tert-butanol	medium	
3,3'-dithiobis[2-methyl]-furan	medium	medium
m-aminophenylacetylene	medium	medium
2,5-dihydro-3,4-dimethyl-furan	medium	medium
2-acetylthiazole	medium	medium
cyclohexane	medium	
ethyl tert-butyl ether	medium	
carbon disulfide	medium	medium
thiazole	medium	medium
acetonitrile	medium	large
2-pentyl-furan	medium	Low
3-thiophenecarboxaldehyde	medium	medium
2-methyl-butanal	medium	medium
thiazole	medium	large
2-methyl-3-furanthiol	large	large
2-propenal	large	large
3-methyl-2-butenal	large	medium
2-methyl-3-(methylthio) furan	large	large
ethyl acetate	large	medium
methacrolein	large	medium
methyl-thirane	large	large
methional	large	large
methyl alcohol	large	medium
2-butanone	large	Low
2,3-butanedione	large	medium
acetone	large	large
furan	large	medium
benzaldehyde	large	medium
methyl thiolacetate	large	medium
acetaldehyde	very large	very large
2-methyl-propanal	very large	very large
dimethyl trisulfide	very large	very large
3-methyl-butanal	very large	very large
propyl-cyclopropane		medium
(E)-2-octenal		medium
2-n-propylaziridine		medium
thirane		medium
ethyl formate		medium
methyl vinyl ketone		medium
2-propenoic acid, ethyl ester		medium
1-nonanol		large
1-octene		large
1-heptanol		large
1-dodecene		large
phorone		very large

Example 14. The Combination of Precursors with Heme Protein Drives Flavor Reactions

Three samples were compared: precursor mix alone, 1% heme protein alone, and precursor mix with 1% heme. The precursor mix was made of glucose (20 mM), ribose (20 mM), cysteine (10 mM), thiamine (1 mM), and glutamic acid (1 mM). Reactions were all at pH 6.0, prepared and heated to 150° C. for 3 minutes. These three samples were run in duplicate. These samples were evaluated by GCMS for the flavor compounds generated. Characteristic flavor and fragrance components were mostly produced during the cooking process where precursors could react with the heme-protein. These samples were evaluated by GCMS for the flavor compounds generated and evaluated for the sensory experience. Volatile chemicals were isolated from the head space around the flavor reaction. The flavor compounds created in each sample is indicated in Table 18. As shown most of the flavor molecules were created on when the precursors are combined with the heme protein.

TABLE 18

Compound	Precursor mix	LegH	Precursor mix + Leg H
carbon disulfide	medium	medium	high
isopropyl alcohol	medium	medium	low
30 2-methyl-furan	low	low	low
butanal	low		medium
thiophene	low		low
2,3-butanedione	low	low	high
furan	low		medium
2,4-dimethyl-1-heptene		high	high
35 acetone		high	high
dimethyl trisulfide		medium	medium
2-methyl-heptane		medium	medium
2-pentanone		medium	
pentanal		medium	medium
2-pentyl-furan		medium	medium
40 2-methyl-propanal		low	high
2-acetyl-1-propene		low	low
2-methyl-butanal		low	medium
1,3-dimethyl-benzene		low	low
octane		low	low
benzene		low	low
benzaldehyde			very high
45 2-butanone			very high
furfural			very high
thiazole			high
nonanal			high
thiazole			high
2-acetylthiazole			medium
50 3-methyl-butanal			medium
(Z)-2-heptenal			medium
heptanal			medium
methyl-thirane			medium
3-ethyl-pentane			medium
phenylacetaldehyde			medium
55 2-hexyl-furan			medium
2-nonanone			medium
propanal			medium
pyrazine			medium
(Z)-2-heptenal			medium
2-methyl-1-heptene			medium
2-ethyl-furan			medium
60 octanal			medium
(E)-4-octene			low
(E)-2-octenal			low
2-methyl-thiazole			low
2-propenal			low
1-octen-3-one			low
65 1-octene			low
2-octanone			low

TABLE 18-continued

Flavor molecules created by the combination of LegH and precursor mix.			
Compound	Precursor mix	LegH	Precursor mix + Leg H
dimethyl sulfide			low
3-pentyl-furan			low
2-n-octylfuran			low
2-pentyl-thiophene			low

## Other Embodiments

It is to be understood that while the invention has been described in conjunction with the detailed description thereof, the foregoing description is intended to illustrate and not limit the scope of the invention, which is defined by the scope of the appended claims. Other aspects, advantages, and modifications are within the scope of the following claims.

## SEQUENCE LISTING

&lt;160&gt; NUMBER OF SEQ ID NOS: 27

<210> SEQ ID NO 1  
<211> LENGTH: 161  
<212> TYPE: PRT  
<213> ORGANISM: Vigna radiata

&lt;400&gt; SEQUENCE: 1

Met	Thr	Thr	Thr	Leu	Glu	Arg	Gly	Phe	Thr	Glu	Glu	Gln	Glu	Ala	Leu
1				5				10						15	

Val	Val	Lys	Ser	Trp	Asn	Val	Met	Lys	Lys	Asn	Ser	Gly	Glu	Leu	Gly
				20			25						30		

Leu	Lys	Phe	Phe	Leu	Lys	Ile	Phe	Glu	Ile	Ala	Pro	Ser	Ala	Gln	Lys
	35				40				45						

Leu	Phe	Ser	Phe	Leu	Arg	Asp	Ser	Thr	Val	Pro	Leu	Glu	Gln	Asn	Pro
	50				55				60						

Lys	Leu	Lys	Pro	His	Ala	Val	Ser	Val	Phe	Val	Met	Thr	Cys	Asp	Ser
65						70			75			80			

Ala	Val	Gln	Leu	Arg	Lys	Ala	Gly	Lys	Val	Thr	Val	Arg	Glu	Ser	Asn
		85			90					95					

Leu	Lys	Lys	Leu	Gly	Ala	Thr	His	Phe	Arg	Thr	Gly	Val	Ala	Asn	Glu
	100				105				110						

His	Phe	Glu	Val	Thr	Lys	Phe	Ala	Leu	Leu	Glu	Thr	Ile	Lys	Glu	Ala
	115				120				125						

Val	Pro	Glu	Met	Trp	Ser	Pro	Ala	Met	Lys	Asn	Ala	Trp	Gly	Glu	Ala
130				135				140							

Tyr	Asp	Gln	Leu	Val	Asp	Ala	Ile	Lys	Tyr	Glu	Met	Lys	Pro	Pro	Ser
145					150				155			160			

Ser

<210> SEQ ID NO 2  
<211> LENGTH: 133  
<212> TYPE: PRT  
<213> ORGANISM: Methylacidiphilum infernorum

&lt;400&gt; SEQUENCE: 2

Met	Ile	Asp	Gln	Lys	Glu	Lys	Glu	Leu	Ile	Lys	Glu	Ser	Trp	Lys	Arg
1				5				10				15			

Ile	Glu	Pro	Asn	Lys	Asn	Glu	Ile	Gly	Leu	Leu	Phe	Tyr	Ala	Asn	Leu
	20				25				30						

Phe	Lys	Glu	Glu	Pro	Thr	Val	Ser	Val	Leu	Phe	Gln	Asn	Pro	Ile	Ser
35				40					45						

Ser	Gln	Ser	Arg	Lys	Leu	Met	Gln	Val	Leu	Gly	Ile	Leu	Val	Gln	Gly
50				55					60						

Ile Asp Asn Leu Glu Gly Leu Ile Pro Thr Leu Gln Asp Leu Gly Arg

-continued

65	70	75	80
Arg His Lys Gln Tyr Gly Val Val Asp Ser His Tyr Pro Leu Val Gly			
85	90	95	
Asp Cys Leu Leu Lys Ser Ile Gln Glu Tyr Leu Gly Gln Gly Phe Thr			
100	105	110	
Glu Glu Ala Lys Ala Ala Trp Thr Lys Val Tyr Gly Ile Ala Ala Gln			
115	120	125	
Val Met Thr Ala Glu			
130			

<210> SEQ ID NO 3  
<211> LENGTH: 139  
<212> TYPE: PRT  
<213> ORGANISM: Aquifex aeolicus

<400> SEQUENCE: 3

Met Leu Ser Glu Glu Thr Ile Arg Val Ile Lys Ser Thr Val Pro Leu			
1	5	10	15
Leu Lys Glu His Gly Thr Glu Ile Thr Ala Arg Met Tyr Glu Leu Leu			
20	25	30	
Phe Ser Lys Tyr Pro Lys Thr Lys Glu Leu Phe Ala Gly Ala Ser Glu			
35	40	45	
Glu Gln Pro Lys Lys Leu Ala Asn Ala Ile Ile Ala Tyr Ala Thr Tyr			
50	55	60	
Ile Asp Arg Leu Glu Glu Leu Asp Asn Ala Ile Ser Thr Ile Ala Arg			
65	70	75	80
Ser His Val Arg Arg Asn Val Lys Pro Glu His Tyr Pro Leu Val Lys			
85	90	95	
Glu Cys Leu Leu Gln Ala Ile Glu Val Leu Asn Pro Gly Glu Glu			
100	105	110	
Val Leu Lys Ala Trp Glu Glu Ala Tyr Asp Phe Leu Ala Lys Thr Leu			
115	120	125	
Ile Thr Leu Glu Lys Lys Leu Tyr Ser Gln Pro			
130	135		

<210> SEQ ID NO 4  
<211> LENGTH: 145  
<212> TYPE: PRT  
<213> ORGANISM: Glycine max

<400> SEQUENCE: 4

Met Gly Ala Phe Thr Glu Lys Gln Glu Ala Leu Val Ser Ser Ser Phe			
1	5	10	15
Glu Ala Phe Lys Ala Asn Ile Pro Gln Tyr Ser Val Val Phe Tyr Thr			
20	25	30	
Ser Ile Leu Glu Lys Ala Pro Ala Ala Lys Asp Leu Phe Ser Phe Leu			
35	40	45	
Ser Asn Gly Val Asp Pro Ser Asn Pro Lys Leu Thr Gly His Ala Glu			
50	55	60	
Lys Leu Phe Gly Leu Val Arg Asp Ser Ala Gly Gln Leu Lys Ala Asn			
65	70	75	80
Gly Thr Val Val Ala Asp Ala Ala Leu Gly Ser Ile His Ala Gln Lys			
85	90	95	
Ala Ile Thr Asp Pro Gln Phe Val Val Lys Glu Ala Leu Leu Lys			
100	105	110	
Thr Ile Lys Glu Ala Val Gly Asp Lys Trp Ser Asp Glu Leu Ser Ser			

-continued

115	120	125
Ala Trp Glu Val Ala Tyr Asp Glu Leu Ala Ala Ala Ile Lys Lys Ala		
130	135	140

Phe  
145

<210> SEQ ID NO 5  
<211> LENGTH: 162  
<212> TYPE: PRT  
<213> ORGANISM: Hordeum vulgare

&lt;400&gt; SEQUENCE: 5

Met Ser Ala Ala Glu Gly Ala Val Val Phe Ser Glu Glu Lys Glu Ala			
1	5	10	15

Leu Val Leu Lys Ser Trp Ala Ile Met Lys Lys Asp Ser Ala Asn Leu		
20	25	30

Gly Leu Arg Phe Phe Leu Lys Ile Phe Glu Ile Ala Pro Ser Ala Arg		
35	40	45

Gln Met Phe Pro Phe Leu Arg Asp Ser Asp Val Pro Leu Glu Thr Asn		
50	55	60

Pro Lys Leu Lys Thr His Ala Val Ser Val Phe Val Met Thr Cys Glu			
65	70	75	80

Ala Ala Ala Gln Leu Arg Lys Ala Gly Lys Ile Thr Val Arg Glu Thr		
85	90	95

Thr Leu Lys Arg Leu Gly Gly Thr His Leu Lys Tyr Gly Val Ala Asp		
100	105	110

Gly His Phe Glu Val Thr Arg Phe Ala Leu Leu Glu Thr Ile Lys Glu		
115	120	125

Ala Leu Pro Ala Asp Met Trp Gly Pro Glu Met Arg Asn Ala Trp Gly		
130	135	140

Glu Ala Tyr Asp Gln Leu Val Ala Ala Ile Lys Gln Glu Met Lys Pro			
145	150	155	160

Ala Glu

<210> SEQ ID NO 6  
<211> LENGTH: 1153  
<212> TYPE: PRT  
<213> ORGANISM: Magnaporthe oryzae

&lt;400&gt; SEQUENCE: 6

Met Asp Gly Ala Val Arg Leu Asp Trp Thr Gly Leu Asp Leu Thr Gly			
1	5	10	15

His Glu Ile His Asp Gly Val Pro Ile Ala Ser Arg Val Gln Val Met		
20	25	30

Val Ser Phe Pro Leu Phe Lys Asp Gln His Ile Ile Met Ser Ser Lys		
35	40	45

Glu Ser Pro Ser Arg Lys Ser Ser Thr Ile Gly Gln Ser Thr Arg Asn		
50	55	60

Gly Ser Cys Gln Ala Asp Thr Gln Lys Gly Gln Leu Pro Pro Val Gly			
65	70	75	80

Glu Lys Pro Lys Pro Val Lys Glu Asn Pro Met Lys Lys Leu Lys Glu		
85	90	95

Met Ser Gln Arg Pro Leu Pro Thr Gln His Gly Asp Gly Thr Tyr Pro		
100	105	110

Thr Glu Lys Leu Thr Gly Ile Gly Glu Asp Leu Lys His Ile Arg		
115	120	125

-continued

Gly Tyr Asp Val Lys Thr Leu Leu Ala Met Val Lys Ser Lys Leu Lys  
130 135 140

Gly Glu Lys Leu Lys Asp Asp Lys Thr Met Leu Met Glu Arg Val Met  
145 150 155 160

Gln Leu Val Ala Arg Leu Pro Thr Glu Ser Lys Lys Arg Ala Glu Leu  
165 170 175

Thr Asp Ser Leu Ile Asn Glu Leu Trp Glu Ser Leu Asp His Pro Pro  
180 185 190

Leu Asn Tyr Leu Gly Pro Glu His Ser Tyr Arg Thr Pro Asp Gly Ser  
195 200 205

Tyr Asn His Pro Phe Asn Pro Gln Leu Gly Ala Ala Gly Ser Arg Tyr  
210 215 220

Ala Arg Ser Val Ile Pro Thr Val Thr Pro Pro Gly Ala Leu Pro Asp  
225 230 235 240

Pro Gly Leu Ile Phe Asp Ser Ile Met Gly Arg Thr Pro Asn Ser Tyr  
245 250 255

Arg Lys His Pro Asn Asn Val Ser Ser Ile Leu Trp Tyr Trp Ala Thr  
260 265 270

Ile Ile Ile His Asp Ile Phe Trp Thr Asp Pro Arg Asp Ile Asn Thr  
275 280 285

Asn Lys Ser Ser Ser Tyr Leu Asp Leu Ala Pro Leu Tyr Gly Asn Ser  
290 295 300

Gln Glu Met Gln Asp Ser Ile Arg Thr Phe Lys Asp Gly Arg Met Lys  
305 310 315 320

Pro Asp Cys Tyr Ala Asp Lys Arg Leu Ala Gly Met Pro Pro Gly Val  
325 330 335

Ser Val Leu Leu Ile Met Phe Asn Arg Phe His Asn His Val Ala Glu  
340 345 350

Asn Leu Ala Leu Ile Asn Glu Gly Arg Phe Asn Lys Pro Ser Asp  
355 360 365

Leu Leu Glu Gly Glu Ala Arg Glu Ala Ala Trp Lys Lys Tyr Asp Asn  
370 375 380

Asp Leu Phe Gln Val Ala Arg Leu Val Thr Ser Gly Leu Tyr Ile Asn  
385 390 395 400

Ile Thr Leu Val Asp Tyr Val Arg Asn Ile Val Asn Leu Asn Arg Val  
405 410 415

Asp Thr Thr Trp Thr Leu Asp Pro Arg Gln Asp Ala Gly Ala His Val  
420 425 430

Gly Thr Ala Asp Gly Ala Glu Arg Gly Thr Gly Asn Ala Val Ser Ala  
435 440 445

Glu Phe Asn Leu Cys Tyr Arg Trp His Ser Cys Ile Ser Glu Lys Asp  
450 455 460

Ser Lys Phe Val Glu Ala Gln Phe Gln Asn Ile Phe Gly Lys Pro Ala  
465 470 475 480

Ser Glu Val Arg Pro Asp Glu Met Trp Lys Gly Phe Ala Lys Met Glu  
485 490 495

Gln Asn Thr Pro Ala Asp Pro Gly Gln Arg Thr Phe Gly Gly Phe Lys  
500 505 510

Arg Gly Pro Asp Gly Lys Phe Asp Asp Asp Asp Leu Val Arg Cys Ile  
515 520 525

Ser Glu Ala Val Glu Asp Val Ala Gly Ala Phe Gly Ala Arg Asn Val  
530 535 540

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Pro Gln Ala Met Lys Val Val Glu Thr Met Gly Ile Ile Gln Gly Arg  
 545 550 555 560  
 Lys Trp Asn Val Ala Gly Leu Asn Glu Phe Arg Lys His Phe His Leu  
 565 570 575  
 Lys Pro Tyr Ser Thr Phe Glu Asp Ile Asn Ser Asp Pro Gly Val Ala  
 580 585 590  
 Glu Ala Leu Arg Arg Leu Tyr Asp His Pro Asp Asn Val Glu Leu Tyr  
 595 600 605  
 Pro Gly Leu Val Ala Glu Glu Asp Lys Gln Pro Met Val Pro Gly Val  
 610 615 620  
 Gly Ile Ala Pro Thr Tyr Thr Ile Ser Arg Val Val Leu Ser Asp Ala  
 625 630 635 640  
 Val Cys Leu Val Arg Gly Asp Arg Phe Tyr Thr Thr Asp Phe Thr Pro  
 645 650 655  
 Arg Asn Leu Thr Asn Trp Gly Tyr Lys Glu Val Asp Tyr Asp Leu Ser  
 660 665 670  
 Val Asn His Gly Cys Val Phe Tyr Lys Leu Phe Ile Arg Ala Phe Pro  
 675 680 685  
 Asn His Phe Lys Gln Asn Ser Val Tyr Ala His Tyr Pro Met Val Val  
 690 695 700  
 Pro Ser Glu Asn Lys Arg Ile Leu Glu Ala Leu Gly Arg Ala Asp Leu  
 705 710 715 720  
 Phe Asp Phe Glu Ala Pro Lys Tyr Ile Pro Pro Arg Val Asn Ile Thr  
 725 730 735  
 Ser Tyr Gly Gly Ala Glu Tyr Ile Leu Glu Thr Gln Glu Lys Tyr Lys  
 740 745 750  
 Val Thr Trp His Glu Gly Leu Gly Phe Leu Met Gly Glu Gly Leu  
 755 760 765  
 Lys Phe Met Leu Ser Gly Asp Asp Pro Leu His Ala Gln Gln Arg Lys  
 770 775 780  
 Cys Met Ala Ala Gln Leu Tyr Lys Asp Gly Trp Thr Glu Ala Val Lys  
 785 790 795 800  
 Ala Phe Tyr Ala Gly Met Met Glu Glu Leu Leu Val Ser Lys Ser Tyr  
 805 810 815  
 Phe Leu Gly Asn Asn Lys His Arg His Val Asp Ile Ile Arg Asp Val  
 820 825 830  
 Gly Asn Met Val His Val His Phe Ala Ser Gln Val Phe Gly Leu Pro  
 835 840 845  
 Leu Lys Thr Ala Lys Asn Pro Thr Gly Val Phe Thr Glu Gln Glu Met  
 850 855 860  
 Tyr Gly Ile Leu Ala Ala Ile Phe Thr Ile Phe Phe Asp Leu Asp  
 865 870 875 880  
 Pro Ser Lys Ser Phe Pro Leu Arg Thr Lys Thr Arg Glu Val Cys Gln  
 885 890 895  
 Lys Leu Ala Lys Leu Val Glu Ala Asn Val Lys Leu Ile Asn Lys Ile  
 900 905 910  
 Pro Trp Ser Arg Gly Met Phe Val Gly Lys Pro Ala Lys Asp Glu Pro  
 915 920 925  
 Leu Ser Ile Tyr Gly Lys Thr Met Ile Lys Gly Leu Lys Ala His Gly  
 930 935 940  
 Leu Ser Asp Tyr Asp Ile Ala Trp Ser His Val Val Pro Thr Ser Gly  
 945 950 955 960  
 Ala Met Val Pro Asn Gln Ala Gln Val Phe Ala Gln Ala Val Asp Tyr

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965	970	975
Tyr Leu Ser Pro Ala Gly Met His Tyr Ile Pro Glu Ile His Met Val		
980	985	990
Ala Leu Gln Pro Ser Thr Pro Glu Thr Asp Ala Leu Leu Leu Gly Tyr		
995	1000	1005
Ala Met Glu Gly Ile Arg Leu Ala Gly Thr Phe Gly Ser Tyr Arg Glu		
1010	1015	1020
Ala Ala Val Asp Asp Val Val Lys Glu Asp Asn Gly Arg Gln Val Pro		
1025	1030	1035
1040		
Val Lys Ala Gly Asp Arg Val Phe Val Ser Phe Val Asp Ala Ala Arg		
1045	1050	1055
Asp Pro Lys His Phe Pro Asp Pro Glu Val Val Asn Pro Arg Arg Pro		
1060	1065	1070
Ala Lys Lys Tyr Ile His Tyr Gly Val Gly Pro His Ala Cys Leu Gly		
1075	1080	1085
Arg Asp Ala Ser Gln Ile Ala Ile Thr Glu Met Phe Arg Cys Leu Phe		
1090	1095	1100
Arg Arg Arg Asn Val Arg Arg Val Pro Gly Pro Gln Gly Glu Leu Lys		
1105	1110	1115
1120		
Lys Val Pro Arg Pro Gly Gly Phe Tyr Val Tyr Met Arg Glu Asp Trp		
1125	1130	1135
Gly Gly Leu Phe Pro Phe Pro Val Thr Met Arg Val Met Trp Asp Asp		
1140	1145	1150

Glu

<210> SEQ ID NO 7  
<211> LENGTH: 530  
<212> TYPE: PRT  
<213> ORGANISM: Fusarium oxysporum

&lt;400&gt; SEQUENCE: 7

Met Lys Gly Ser Ala Thr Leu Ala Phe Ala Leu Val Gln Phe Ser Ala		
1	5	10
		15
Ala Ser Gln Leu Val Trp Pro Ser Lys Trp Asp Glu Val Glu Asp Leu		
20	25	30
Leu Tyr Met Gln Gly Gly Phe Asn Lys Arg Gly Phe Ala Asp Ala Leu		
35	40	45
Arg Thr Cys Glu Phe Gly Ser Asn Val Pro Gly Thr Gln Asn Thr Ala		
50	55	60
Glu Trp Leu Arg Thr Ala Phe His Asp Ala Ile Thr His Asp Ala Lys		
65	70	75
		80
Ala Gly Thr Gly Gly Leu Asp Ala Ser Ile Tyr Trp Glu Ser Ser Arg		
85	90	95
Pro Glu Asn Pro Gly Lys Ala Phe Asn Asn Thr Phe Gly Phe Phe Ser		
100	105	110
Gly Phe His Asn Pro Arg Ala Thr Ala Ser Asp Leu Thr Ala Leu Gly		
115	120	125
Thr Val Leu Ala Val Gly Ala Cys Asn Gly Pro Arg Ile Pro Phe Arg		
130	135	140
Ala Gly Arg Ile Asp Ala Tyr Lys Ala Gly Pro Ala Gly Val Pro Glu		
145	150	155
		160
Pro Ser Thr Asn Leu Lys Asp Thr Phe Ala Ala Phe Thr Lys Ala Gly		
165	170	175
Phe Thr Lys Glu Glu Met Thr Ala Met Val Ala Cys Gly His Ala Ile		

-continued

180	185	190
Gly	Gly	Val His Ser Val Asp Phe Pro Glu Ile Val Gly Ile Lys Ala
195	200	205
Asp	Pro Asn Asn Asp Thr Asn Val Pro Phe Gln Lys Asp Val Ser Ser	
210	215	220
Phe	His Asn Gly Ile Val Thr Glu Tyr Leu Ala Gly Thr Ser Lys Asn	
225	230	235
240		
Pro	Leu Val Ala Ser Lys Asn Ala Thr Phe His Ser Asp Lys Arg Ile	
245	250	255
Phe	Asp Asn Asp Lys Ala Thr Met Lys Lys Leu Ser Thr Lys Ala Gly	
260	265	270
Phe	Asn Ser Met Cys Ala Asp Ile Leu Thr Arg Met Ile Asp Thr Val	
275	280	285
Pro	Lys Ser Val Gln Leu Thr Pro Val Leu Glu Ala Tyr Asp Val Arg	
290	295	300
Pro	Tyr Ile Thr Glu Leu Ser Leu Asn Asn Lys Asn Lys Ile His Phe	
305	310	315
320		
Thr	Gly Ser Val Arg Val Arg Ile Thr Asn Asn Ile Arg Asp Asn Asn	
325	330	335
Asp	Leu Ala Ile Asn Leu Ile Tyr Val Gly Arg Asp Gly Lys Lys Val	
340	345	350
Thr	Val Pro Thr Gln Gln Val Thr Phe Gln Gly Gly Thr Ser Phe Gly	
355	360	365
Ala	Gly Glu Val Phe Ala Asn Phe Glu Phe Asp Thr Thr Met Asp Ala	
370	375	380
Lys	Asn Gly Ile Thr Lys Phe Phe Ile Gln Glu Val Lys Pro Ser Thr	
385	390	395
400		
Lys	Ala Thr Val Thr His Asp Asn Gln Lys Thr Gly Gly Tyr Lys Val	
405	410	415
Asp	Asp Thr Val Leu Tyr Gln Leu Gln Gln Ser Cys Ala Val Leu Glu	
420	425	430
Lys	Leu Pro Asn Ala Pro Leu Val Val Thr Ala Met Val Arg Asp Ala	
435	440	445
Arg	Ala Lys Asp Ala Leu Thr Leu Arg Val Ala His Lys Lys Pro Val	
450	455	460
Lys	Gly Ser Ile Val Pro Arg Phe Gln Thr Ala Ile Thr Asn Phe Lys	
465	470	475
480		
Ala	Thr Gly Lys Ser Ser Gly Tyr Thr Gly Phe Gln Ala Lys Thr	
485	490	495
Met	Phe Glu Glu Gln Ser Thr Tyr Phe Asp Ile Val Leu Gly Gly Ser	
500	505	510
Pro	Ala Ser Gly Val Gln Phe Leu Thr Ser Gln Ala Met Pro Ser Gln	
515	520	525
Cys	Ser	
530		

&lt;210&gt; SEQ\_ID NO 8

&lt;211&gt; LENGTH: 358

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Fusarium graminearum

&lt;400&gt; SEQUENCE: 8

Met	Ala	Ser	Ala	Thr	Arg	Gln	Phe	Ala	Arg	Ala	Ala	Thr	Arg	Ala	Thr
1				5			10					15			

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Arg Asn Gly Phe Ala Ile Ala Pro Arg Gln Val Ile Arg Gln Gln Gly  
20 25 30

Arg Arg Tyr Tyr Ser Ser Glu Pro Ala Gln Lys Ser Ser Ser Ala Trp  
35 40 45

Ile Trp Leu Thr Gly Ala Ala Val Ala Gly Gly Ala Gly Tyr Tyr Phe  
50 55 60

Tyr Gly Asn Ser Ala Ser Ser Ala Thr Ala Lys Val Phe Asn Pro Ser  
65 70 75 80

Lys Glu Asp Tyr Gln Lys Val Tyr Asn Glu Ile Ala Ala Arg Leu Glu  
85 90 95

Glu Lys Asp Asp Tyr Asp Asp Gly Ser Tyr Gly Pro Val Leu Val Arg  
100 105 110

Leu Ala Trp His Ala Ser Gly Thr Tyr Asp Lys Glu Thr Gly Thr Gly  
115 120 125

Gly Ser Asn Gly Ala Thr Met Arg Phe Ala Pro Glu Ser Asp His Gly  
130 135 140

Ala Asn Ala Gly Leu Ala Ala Ala Arg Asp Phe Leu Gln Pro Val Lys  
145 150 155 160

Glu Lys Phe Pro Trp Ile Thr Tyr Ser Asp Leu Trp Ile Leu Ala Gly  
165 170 175

Val Cys Ala Ile Gln Glu Met Leu Gly Pro Ala Ile Pro Tyr Arg Pro  
180 185 190

Gly Arg Ser Asp Arg Asp Val Ser Gly Cys Thr Pro Asp Gly Arg Leu  
195 200 205

Pro Asp Ala Ser Lys Arg Gln Asp His Leu Arg Gly Ile Phe Gly Arg  
210 215 220

Met Gly Phe Asn Asp Gln Glu Ile Val Ala Leu Ser Gly Ala His Ala  
225 230 235 240

Leu Gly Arg Cys His Thr Asp Arg Ser Gly Tyr Ser Gly Pro Trp Thr  
245 250 255

Phe Ser Pro Thr Val Leu Thr Asn Asp Tyr Phe Arg Leu Leu Val Glu  
260 265 270

Glu Lys Trp Gln Trp Lys Lys Trp Asn Gly Pro Ala Gln Tyr Glu Asp  
275 280 285

Lys Ser Thr Lys Ser Leu Met Met Leu Pro Ser Asp Ile Ala Leu Ile  
290 295 300

Glu Asp Lys Lys Phe Lys Pro Trp Val Glu Lys Tyr Ala Lys Asp Asn  
305 310 315 320

Asp Ala Phe Phe Lys Asp Phe Ser Asn Val Val Leu Arg Leu Phe Glu  
325 330 335

Leu Gly Val Pro Phe Ala Gln Gly Thr Glu Asn Gln Arg Trp Thr Phe  
340 345 350

Lys Pro Thr His Gln Glu  
355

<210> SEQ ID NO 9

<211> LENGTH: 122

<212> TYPE: PRT

<213> ORGANISM: Chlamydomonas eugametos

<400> SEQUENCE: 9

Met Ser Leu Phe Ala Lys Leu Gly Arg Glu Ala Val Glu Ala Ala  
1 5 10 15

Val Asp Lys Phe Tyr Asn Lys Ile Val Ala Asp Pro Thr Val Ser Thr  
20 25 30

-continued

Tyr Phe Ser Asn Thr Asp Met Lys Val Gln Arg Ser Lys Gln Phe Ala  
 35 40 45

Phe Leu Ala Tyr Ala Leu Gly Gly Ala Ser Glu Trp Lys Gly Lys Asp  
 50 55 60

Met Arg Thr Ala His Lys Asp Leu Val Pro His Leu Ser Asp Val His  
 65 70 75 80

Phe Gln Ala Val Ala Arg His Leu Ser Asp Thr Leu Thr Glu Leu Gly  
 85 90 95

Val Pro Pro Glu Asp Ile Thr Asp Ala Met Ala Val Val Ala Ser Thr  
 100 105 110

Arg Thr Glu Val Leu Asn Met Pro Gln Gln  
 115 120

<210> SEQ ID NO 10  
 <211> LENGTH: 121  
 <212> TYPE: PRT  
 <213> ORGANISM: Tetrahymena pyriformis  
 <400> SEQUENCE: 10

Met Asn Lys Pro Gln Thr Ile Tyr Glu Lys Leu Gly Gly Glu Asn Ala  
 1 5 10 15

Met Lys Ala Ala Val Pro Leu Phe Tyr Lys Lys Val Leu Ala Asp Glu  
 20 25 30

Arg Val Lys His Phe Phe Lys Asn Thr Asp Met Asp His Gln Thr Lys  
 35 40 45

Gln Gln Thr Asp Phe Leu Thr Met Leu Leu Gly Gly Pro Asn His Tyr  
 50 55 60

Lys Gly Lys Asn Met Thr Glu Ala His Lys Gly Met Asn Leu Gln Asn  
 65 70 75 80

Leu His Phe Asp Ala Ile Ile Glu Asn Leu Ala Ala Thr Leu Lys Glu  
 85 90 95

Leu Gly Val Thr Asp Ala Val Ile Asn Glu Ala Ala Lys Val Ile Glu  
 100 105 110

His Thr Arg Lys Asp Met Leu Gly Lys  
 115 120

<210> SEQ ID NO 11  
 <211> LENGTH: 117  
 <212> TYPE: PRT  
 <213> ORGANISM: Paramecium caudatum  
 <400> SEQUENCE: 11

Met Ser Leu Phe Glu Gln Leu Gly Gly Gln Ala Ala Val Gln Ala Val  
 1 5 10 15

Thr Ala Gln Phe Tyr Ala Asn Ile Gln Ala Asp Ala Thr Val Ala Thr  
 20 25 30

Phe Phe Asn Gly Ile Asp Met Pro Asn Gln Thr Asn Lys Thr Ala Ala  
 35 40 45

Phe Leu Cys Ala Ala Leu Gly Gly Pro Asn Ala Trp Thr Gly Arg Asn  
 50 55 60

Leu Lys Glu Val His Ala Asn Met Gly Val Ser Asn Ala Gln Phe Thr  
 65 70 75 80

Thr Val Ile Gly His Leu Arg Ser Ala Leu Thr Gly Ala Gly Val Ala  
 85 90 95

Ala Ala Leu Val Glu Gln Thr Val Ala Val Ala Glu Thr Val Arg Gly  
 100 105 110

-continued

Asp Val Val Thr Val  
115

<210> SEQ ID NO 12  
<211> LENGTH: 147  
<212> TYPE: PRT  
<213> ORGANISM: Aspergillus niger

&lt;400&gt; SEQUENCE: 12

Met Pro Leu Thr Pro Glu Gln Ile Lys Ile Ile Lys Ala Thr Val Pro  
1 5 10 15

Val Leu Gln Glu Tyr Gly Thr Lys Ile Thr Thr Ala Phe Tyr Met Asn  
20 25 30

Met Ser Thr Val His Pro Glu Leu Asn Ala Val Phe Asn Thr Ala Asn  
35 40 45

Gln Val Lys Gly His Gln Ala Arg Ala Leu Ala Gly Ala Leu Phe Ala  
50 55 60

Tyr Ala Ser His Ile Asp Asp Leu Gly Ala Leu Gly Pro Ala Val Glu  
65 70 75 80

Leu Ile Cys Asn Lys His Ala Ser Leu Tyr Ile Gln Ala Asp Glu Tyr  
85 90 95

Lys Ile Val Gly Lys Tyr Leu Leu Glu Ala Met Lys Glu Val Leu Gly  
100 105 110

Asp Ala Cys Thr Asp Asp Ile Leu Asp Ala Trp Gly Ala Ala Tyr Trp  
115 120 125

Ala Leu Ala Asp Ile Met Ile Asn Arg Glu Ala Ala Leu Tyr Lys Gln  
130 135 140

Ser Gln Gly  
145

<210> SEQ ID NO 13  
<211> LENGTH: 165  
<212> TYPE: PRT  
<213> ORGANISM: Zea mays

&lt;400&gt; SEQUENCE: 13

Met Ala Leu Ala Glu Ala Asp Asp Gly Ala Val Val Phe Gly Glu Glu  
1 5 10 15

Gln Glu Ala Leu Val Leu Lys Ser Trp Ala Val Met Lys Lys Asp Ala  
20 25 30

Ala Asn Leu Gly Leu Arg Phe Phe Leu Lys Val Phe Glu Ile Ala Pro  
35 40 45

Ser Ala Glu Gln Met Phe Ser Phe Leu Arg Asp Ser Asp Val Pro Leu  
50 55 60

Glu Lys Asn Pro Lys Leu Lys Thr His Ala Met Ser Val Phe Val Met  
65 70 75 80

Thr Cys Glu Ala Ala Ala Gln Leu Arg Lys Ala Gly Lys Val Thr Val  
85 90 95

Arg Glu Thr Thr Leu Lys Arg Leu Gly Ala Thr His Leu Arg Tyr Gly  
100 105 110

Val Ala Asp Gly His Phe Glu Val Thr Gly Phe Ala Leu Glu Thr  
115 120 125

Ile Lys Glu Ala Leu Pro Ala Asp Met Trp Ser Leu Glu Met Lys Lys  
130 135 140

Ala Trp Ala Glu Ala Tyr Ser Gln Leu Val Ala Ala Ile Lys Arg Glu  
145 150 155 160

-continued

Met Lys Pro Asp Ala  
165

<210> SEQ ID NO 14  
<211> LENGTH: 169  
<212> TYPE: PRT  
<213> ORGANISM: Oryza sativa subsp. japonica

&lt;400&gt; SEQUENCE: 14

Met Ala Leu Val Glu Gly Asn Asn Gly Val Ser Gly Gly Ala Val Ser  
1               5               10               15

Phe Ser Glu Glu Gln Glu Ala Leu Val Leu Lys Ser Trp Ala Ile Met  
20              25              30

Lys Lys Asp Ser Ala Asn Ile Gly Leu Arg Phe Phe Leu Lys Ile Phe  
35              40              45

Glu Val Ala Pro Ser Ala Ser Gln Met Phe Ser Phe Leu Arg Asn Ser  
50              55              60

Asp Val Pro Leu Glu Lys Asn Pro Lys Leu Lys Thr His Ala Met Ser  
65              70              75              80

Val Phe Val Met Thr Cys Glu Ala Ala Ala Gln Leu Arg Lys Ala Gly  
85              90              95

Lys Val Thr Val Arg Asp Thr Thr Leu Lys Arg Leu Gly Ala Thr His  
100             105             110

Phe Lys Tyr Gly Val Gly Asp Ala His Phe Glu Val Thr Arg Phe Ala  
115             120             125

Leu Leu Glu Thr Ile Lys Glu Ala Val Pro Val Asp Met Trp Ser Pro  
130             135             140

Ala Met Lys Ser Ala Trp Ser Glu Ala Tyr Asn Gln Leu Val Ala Ala  
145             150             155             160

Ile Lys Gln Glu Met Lys Pro Ala Glu  
165

<210> SEQ ID NO 15  
<211> LENGTH: 160  
<212> TYPE: PRT  
<213> ORGANISM: Arabidopsis thaliana

&lt;400&gt; SEQUENCE: 15

Met Glu Ser Glu Gly Lys Ile Val Phe Thr Glu Glu Gln Glu Ala Leu  
1               5               10               15

Val Val Lys Ser Trp Ser Val Met Lys Lys Asn Ser Ala Glu Leu Gly  
20              25              30

Leu Lys Leu Phe Ile Lys Ile Phe Glu Ile Ala Pro Thr Thr Lys Lys  
35              40              45

Met Phe Ser Phe Leu Arg Asp Ser Pro Ile Pro Ala Glu Gln Asn Pro  
50              55              60

Lys Leu Lys Pro His Ala Met Ser Val Phe Val Met Cys Cys Glu Ser  
65              70              75              80

Ala Val Gln Leu Arg Lys Thr Gly Lys Val Thr Val Arg Glu Thr Thr  
85              90              95

Leu Lys Arg Leu Gly Ala Ser His Ser Lys Tyr Gly Val Val Asp Glu  
100             105             110

His Phe Glu Val Ala Lys Tyr Ala Leu Leu Glu Thr Ile Lys Glu Ala  
115             120             125

Val Pro Glu Met Trp Ser Pro Glu Met Lys Val Ala Trp Gly Gln Ala  
130             135             140

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Tyr Asp His Leu Val Ala Ala Ile Lys Ala Glu Met Asn Leu Ser Asn  
 145                150                155                160

&lt;210&gt; SEQ ID NO 16

&lt;211&gt; LENGTH: 147

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Pisum sativum

&lt;400&gt; SEQUENCE: 16

Met Gly Phe Thr Asp Lys Gln Glu Ala Leu Val Asn Ser Ser Trp Glu  
 1                5                10                15

Ser Phe Lys Gln Asn Leu Ser Gly Asn Ser Ile Leu Phe Tyr Thr Ile  
 20                25                30

Ile Leu Glu Lys Ala Pro Ala Ala Lys Gly Leu Phe Ser Phe Leu Lys  
 35                40                45

Asp Thr Ala Gly Val Glu Asp Ser Pro Lys Leu Gln Ala His Ala Glu  
 50                55                60

Gln Val Phe Gly Leu Val Arg Asp Ser Ala Ala Gln Leu Arg Thr Lys  
 65                70                75                80

Gly Glu Val Val Leu Gly Asn Ala Thr Leu Gly Ala Ile His Val Gln  
 85                90                95

Arg Gly Val Thr Asp Pro His Phe Val Val Val Lys Glu Ala Leu Leu  
 100                105                110

Gln Thr Ile Lys Lys Ala Ser Gly Asn Asn Trp Ser Glu Glu Leu Asn  
 115                120                125

Thr Ala Trp Glu Val Ala Tyr Asp Gly Leu Ala Thr Ala Ile Lys Lys  
 130                135                140

Ala Met Thr  
 145

&lt;210&gt; SEQ ID NO 17

&lt;211&gt; LENGTH: 145

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Vigna unguiculata

&lt;400&gt; SEQUENCE: 17

Met Val Ala Phe Ser Asp Lys Gln Glu Ala Leu Val Asn Gly Ala Tyr  
 1                5                10                15

Glu Ala Phe Lys Ala Asn Ile Pro Lys Tyr Ser Val Val Phe Tyr Thr  
 20                25                30

Thr Ile Leu Glu Lys Ala Pro Ala Ala Lys Asn Leu Phe Ser Phe Leu  
 35                40                45

Ala Asn Gly Val Asp Ala Thr Asn Pro Lys Leu Thr Gly His Ala Glu  
 50                55                60

Lys Leu Phe Gly Leu Val Arg Asp Ser Ala Ala Gln Leu Arg Ala Ser  
 65                70                75                80

Gly Gly Val Val Ala Asp Ala Ala Leu Gly Ala Val His Ser Gln Lys  
 85                90                95

Ala Val Asn Asp Ala Gln Phe Val Val Lys Glu Ala Leu Val Lys  
 100                105                110

Thr Leu Lys Glu Ala Val Gly Asp Lys Trp Ser Asp Glu Leu Gly Thr  
 115                120                125

Ala Val Glu Leu Ala Tyr Asp Glu Leu Ala Ala Ile Lys Lys Ala  
 130                135                140

Tyr  
 145

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<210> SEQ ID NO 18  
<211> LENGTH: 154  
<212> TYPE: PRT  
<213> ORGANISM: Bos taurus

<400> SEQUENCE: 18

Met	Gly	Leu	Ser	Asp	Gly	Glu	Trp	Gln	Leu	Val	Leu	Asn	Ala	Trp	Gly
1					5			10						15	

Lys Val Glu Ala Asp Val Ala Gly His Gly Gln Glu Val Leu Ile Arg  
20 25 30

Leu Phe Thr Gly His Pro Glu Thr Leu Glu Lys Phe Asp Lys Phe Lys  
35 40 45

His Leu Lys Thr Glu Ala Glu Met Lys Ala Ser Glu Asp Leu Lys Lys  
50 55 60

His Gly Asn Thr Val Leu Thr Ala Leu Gly Gly Ile Leu Lys Lys Lys  
65 70 75 80

Gly His His Glu Ala Glu Val Lys His Leu Ala Glu Ser His Ala Asn  
85 90 95

Lys His Lys Ile Pro Val Lys Tyr Leu Glu Phe Ile Ser Asp Ala Ile  
100 105 110

Ile His Val Leu His Ala Lys His Pro Ser Asp Phe Gly Ala Asp Ala  
115 120 125

Gln Ala Ala Met Ser Lys Ala Leu Glu Leu Phe Arg Asn Asp Met Ala  
130 135 140

Ala Gln Tyr Lys Val Leu Gly Phe His Gly  
145 150

<210> SEQ ID NO 19  
<211> LENGTH: 154  
<212> TYPE: PRT  
<213> ORGANISM: Sus scrofa

<400> SEQUENCE: 19

Met	Gly	Leu	Ser	Asp	Gly	Glu	Trp	Gln	Leu	Val	Leu	Asn	Val	Trp	Gly
1						5		10					15		

Lys Val Glu Ala Asp Val Ala Gly His Gly Gln Glu Val Leu Ile Arg  
20 25 30

Leu Phe Lys Gly His Pro Glu Thr Leu Glu Lys Phe Asp Lys Phe Lys  
35 40 45

His Leu Lys Ser Glu Asp Glu Met Lys Ala Ser Glu Asp Leu Lys Lys  
50 55 60

His Gly Asn Thr Val Leu Thr Ala Leu Gly Gly Ile Leu Lys Lys Lys  
65 70 75 80

Gly His His Glu Ala Glu Leu Thr Pro Leu Ala Gln Ser His Ala Thr  
85 90 95

Lys His Lys Ile Pro Val Lys Tyr Leu Glu Phe Ile Ser Glu Ala Ile  
100 105 110

Ile Gln Val Leu Gln Ser Lys His Pro Gly Asp Phe Gly Ala Asp Ala  
115 120 125

Gln Gly Ala Met Ser Lys Ala Leu Glu Leu Phe Arg Asn Asp Met Ala  
130 135 140

Ala Lys Tyr Lys Glu Leu Gly Phe Gln Gly  
145 150

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<211> LENGTH: 154  
<212> TYPE: PRT  
<213> ORGANISM: Equus caballus

<400> SEQUENCE: 20

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Met Gly Leu Ser Asp Gly Glu Trp Gln Gln Val Leu Asn Val Trp Gly
 1           5          10          15

Lys Val Glu Ala Asp Ile Ala Gly His Gly Gln Glu Val Leu Ile Arg
20          25          30

Leu Phe Thr Gly His Pro Glu Thr Leu Glu Lys Phe Asp Lys Phe Lys
35          40          45

His Leu Lys Thr Glu Ala Glu Met Lys Ala Ser Glu Asp Leu Lys Lys
50          55          60

His Gly Thr Val Val Leu Thr Ala Leu Gly Gly Ile Leu Lys Lys Lys
65          70          75          80

Gly His His Glu Ala Glu Leu Lys Pro Leu Ala Gln Ser His Ala Thr
85          90          95

Lys His Lys Ile Pro Ile Lys Tyr Leu Glu Phe Ile Ser Asp Ala Ile
100         105         110

Ile His Val Leu His Ser Lys His Pro Gly Asp Phe Gly Ala Asp Ala
115         120         125

Gln Gly Ala Met Thr Lys Ala Leu Glu Leu Phe Arg Asn Asp Ile Ala
130         135         140

Ala Lys Tyr Lys Glu Leu Gly Phe Gln Gly
145         150

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<210> SEQ ID NO 21  
<211> LENGTH: 152  
<212> TYPE: PRT  
<213> ORGANISM: Nicotiana benthamiana

<400> SEQUENCE: 21

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Met Ser Ser Phe Thr Glu Glu Gln Glu Ala Leu Val Val Lys Ser Trp
 1           5          10          15

Asp Ser Met Lys Lys Asn Ala Gly Glu Trp Gly Leu Lys Leu Phe Leu
20          25          30

Lys Ile Phe Glu Ile Ala Pro Ser Ala Lys Lys Leu Phe Ser Phe Leu
35          40          45

Lys Asp Ser Asn Val Pro Leu Glu Gln Asn Ala Lys Leu Lys Pro His
50          55          60

Ser Lys Ser Val Phe Val Met Thr Cys Glu Ala Ala Val Gln Leu Arg
65          70          75          80

Lys Ala Gly Lys Val Val Val Arg Asp Ser Thr Leu Lys Lys Leu Gly
85          90          95

Ala Thr His Phe Lys Tyr Gly Val Ala Asp Glu His Phe Glu Val Thr
100         105         110

Lys Phe Ala Leu Leu Glu Thr Ile Lys Glu Ala Val Pro Glu Met Trp
115         120         125

Ser Val Asp Met Lys Asn Ala Trp Gly Glu Ala Phe Asp Gln Leu Val
130         135         140

Asn Ala Ile Lys Thr Glu Met Lys
145         150

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<210> SEQ ID NO 22  
<211> LENGTH: 132  
<212> TYPE: PRT  
<213> ORGANISM: Bacillus subtilis

-continued

&lt;400&gt; SEQUENCE: 22

Met Gly Gln Ser Phe Asn Ala Pro Tyr Glu Ala Ile Gly Glu Glu Leu  
 1               5               10               15

Leu Ser Gln Leu Val Asp Thr Phe Tyr Glu Arg Val Ala Ser His Pro  
 20              25              30

Leu Leu Lys Pro Ile Phe Pro Ser Asp Leu Thr Glu Thr Ala Arg Lys  
 35              40              45

Gln Lys Gln Phe Leu Thr Gln Tyr Leu Gly Gly Pro Pro Leu Tyr Thr  
 50              55              60

Glu Glu His Gly His Pro Met Leu Arg Ala Arg His Leu Pro Phe Pro  
 65              70              75              80

Ile Thr Asn Glu Arg Ala Asp Ala Trp Leu Ser Cys Met Lys Asp Ala  
 85              90              95

Met Asp His Val Gly Leu Glu Gly Ile Arg Glu Phe Leu Phe Gly  
 100             105             110

Arg Leu Glu Leu Thr Ala Arg His Met Val Asn Gln Thr Glu Ala Glu  
 115             120             125

Asp Arg Ser Ser  
 130

&lt;210&gt; SEQ ID NO 23

&lt;211&gt; LENGTH: 131

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Corynebacterium glutamicum

&lt;400&gt; SEQUENCE: 23

Met Thr Thr Ser Glu Asn Phe Tyr Asp Ser Val Gly Gly Glu Glu Thr  
 1               5               10               15

Phe Ser Leu Ile Val His Arg Phe Tyr Glu Gln Val Pro Asn Asp Asp  
 20              25              30

Ile Leu Gly Pro Met Tyr Pro Pro Asp Asp Phe Glu Gly Ala Glu Gln  
 35              40              45

Arg Leu Lys Met Phe Leu Ser Gln Tyr Trp Gly Gly Pro Lys Asp Tyr  
 50              55              60

Gln Glu Gln Arg Gly His Pro Arg Leu Arg Met Arg His Val Asn Tyr  
 65              70              75              80

Pro Ile Gly Val Thr Ala Ala Glu Arg Trp Leu Gln Leu Met Ser Asn  
 85              90              95

Ala Leu Asp Gly Val Asp Leu Thr Ala Glu Gln Arg Glu Ala Ile Trp  
 100             105             110

Glu His Met Val Arg Ala Ala Asp Met Leu Ile Asn Ser Asn Pro Asp  
 115             120             125

Pro His Ala  
 130

&lt;210&gt; SEQ ID NO 24

&lt;211&gt; LENGTH: 124

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Synechocystis sp.

&lt;400&gt; SEQUENCE: 24

Met Ser Thr Leu Tyr Glu Lys Leu Gly Gly Thr Thr Ala Val Asp Leu  
 1               5               10               15

Ala Val Asp Lys Phe Tyr Glu Arg Val Leu Gln Asp Asp Arg Ile Lys  
 20              25              30

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His	Phe	Ala	Asp	Val	Asp	Met	Ala	Lys	Gln	Arg	Ala	His	Gln	Lys
35														
								40						45

Ala	Phe	Leu	Thr	Tyr	Ala	Phe	Gly	Gly	Thr	Asp	Lys	Tyr	Asp	Gly	Arg
50															60

Tyr	Met	Arg	Glu	Ala	His	Lys	Glu	Leu	Val	Glu	Asn	His	Gly	Leu	Asn
65															80
								70		75					

Gly	Glu	His	Phe	Asp	Ala	Val	Ala	Glu	Asp	Leu	Leu	Ala	Thr	Leu	Lys
85															95
								90							

Glu	Met	Gly	Val	Pro	Glu	Asp	Leu	Ile	Ala	Glu	Val	Ala	Ala	Val	Ala
100															110

Gly	Ala	Pro	Ala	His	Lys	Arg	Asp	Val	Leu	Asn	Gln				
115															120

&lt;210&gt; SEQ\_ID NO 25

&lt;211&gt; LENGTH: 183

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Synechococcus sp.

&lt;400&gt; SEQUENCE: 25

Met	Asp	Val	Ala	Leu	Leu	Glu	Lys	Ser	Phe	Glu	Gln	Ile	Ser	Pro	Arg
1									5						15

Ala	Ile	Glu	Phe	Ser	Ala	Ser	Phe	Tyr	Gln	Asn	Leu	Phe	His	His	His
20									25						30

Pro	Glu	Leu	Lys	Pro	Leu	Phe	Ala	Glu	Thr	Ser	Gln	Thr	Ile	Gln	Glu
35									40						45

Lys	Lys	Leu	Ile	Phe	Ser	Leu	Ala	Ala	Ile	Ile	Glu	Asn	Leu	Arg	Asn
50									55						60

Pro	Asp	Ile	Leu	Gln	Pro	Ala	Leu	Lys	Ser	Leu	Gly	Ala	Arg	His	Ala
65									70						80

Glu	Val	Gly	Thr	Ile	Lys	Ser	His	Tyr	Pro	Leu	Val	Gly	Gln	Ala	Leu
85									90						95

Ile	Glu	Thr	Phe	Ala	Glu	Tyr	Leu	Ala	Ala	Asp	Trp	Thr	Glu	Gln	Leu
100									105						110

Ala	Thr	Ala	Trp	Val	Glu	Ala	Tyr	Asp	Val	Ile	Ala	Ser	Thr	Met	Ile
115									120						125

Glu	Gly	Ala	Asp	Asn	Pro	Ala	Ala	Tyr	Leu	Glu	Pro	Glu	Leu	Thr	Phe
130									135						140

Tyr	Glu	Trp	Leu	Asp	Leu	Tyr	Gly	Glu	Ser	Pro	Lys	Val	Arg	Asn	
145									150						160

Ala	Ile	Ala	Thr	Leu	Thr	His	Phe	His	Tyr	Gly	Glu	Asp	Pro	Gln	Asp
165									170						175

Val	Gln	Arg	Asp	Ser	Arg	Gly									
180															

&lt;210&gt; SEQ\_ID NO 26

&lt;211&gt; LENGTH: 118

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Nostoc commune

&lt;400&gt; SEQUENCE: 26

Met	Ser	Thr	Leu	Tyr	Asp	Asn	Ile	Gly	Gly	Gln	Pro	Ala	Ile	Glu	Gln
1									5						15

Val	Val	Asp	Glu	Leu	His	Lys	Arg	Ile	Ala	Thr	Asp	Ser	Leu	Leu	Ala
20									25						30

Pro	Val	Phe	Ala	Gly	Thr	Asp	Met	Val	Lys	Gln	Arg	Asn	His	Leu	Val
35									40						45

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Ala Phe Leu Ala Gln Ile Phe Glu Gly Pro Lys Gln Tyr Gly Gly Arg  
50 55 60

Pro Met Asp Lys Thr His Ala Gly Leu Asn Leu Gln Gln Pro His Phe  
65 70 75 80

Asp Ala Ile Ala Lys His Leu Gly Glu Arg Met Ala Val Arg Gly Val  
85 90 95

Ser Ala Glu Asn Thr Lys Ala Ala Leu Asp Arg Val Thr Asn Met Lys  
100 105 110

Gly Ala Ile Leu Asn Lys  
115

<210> SEQ ID NO 27

<211> LENGTH: 136

<212> TYPE: PRT

<213> ORGANISM: *Bacillus megaterium*

<400> SEQUENCE: 27

Met Arg Glu Lys Ile His Ser Pro Tyr Glu Leu Leu Gly Gly Glu His  
1 5 10 15

Thr Ile Ser Lys Leu Val Asp Ala Phe Tyr Thr Arg Val Gly Gln His  
20 25 30

Pro Glu Leu Ala Pro Ile Phe Pro Asp Asn Leu Thr Glu Thr Ala Arg  
35 40 45

Lys Gln Lys Gln Phe Leu Thr Gln Tyr Leu Gly Gly Pro Ser Leu Tyr  
50 55 60

Thr Glu Glu His Gly His Pro Met Leu Arg Ala Arg His Leu Pro Phe  
65 70 75 80

Glu Ile Thr Pro Ser Arg Ala Lys Ala Trp Leu Thr Cys Met His Glu  
85 90 95

Ala Met Asp Glu Ile Asn Leu Glu Gly Pro Glu Arg Asp Glu Leu Tyr  
100 105 110

His Arg Leu Ile Leu Thr Ala Gln His Met Ile Asn Ser Pro Glu Gln  
115 120 125

Thr Asp Glu Lys Gly Phe Ser His  
130 135

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What is claimed is:

1. A ground beef-like food product comprising:
  - a) 0.1%-5% by weight of a heme-containing protein comprising an amino acid sequence having at least 80% sequence identity to the polypeptide set forth in SEQ ID NO:4;
  - b) a compound selected from glucose, ribose, fructose, lactose, xylose, arabinose, glucose-6-phosphate, maltose, and galactose, and mixtures of two or more thereof;
  - c) at least 10 mM of a compound selected from cysteine, cystine, selenocysteine, thiamine, methionine, and mixtures of two or more thereof; and
  - d) 10% or more by weight of one or more plant proteins, wherein the ground beef-like food product contains no animal products, and wherein cooking the ground beef-like food product results in the production of at least two volatile compounds which have a beef-associated aroma.
2. The ground beef-like food product of claim 1, wherein the heme-containing protein comprises an amino acid sequence having at least 85% sequence identity to the polypeptide set forth in SEQ ID NO:4.
3. The ground beef-like food product of claim 1, wherein the heme-containing protein comprises an amino acid sequence having at least 90% sequence identity to the polypeptide set forth in SEQ ID NO:4.
4. The ground beef-like food product of claim 1, wherein the heme-containing protein comprises an amino acid sequence having at least 95% sequence identity to the polypeptide set forth in SEQ ID NO:4.
5. The ground beef-like food product of claim 1, wherein the heme-containing protein comprises a polypeptide as set forth in SEQ ID NO:4.
6. The ground beef-like food product of claim 1, further comprising one or more of inosine, inosine monophosphate (IMP), guanosine, guanosine monophosphate (GMP), and adenosine monophosphate (AMP).
7. The ground beef-like food product of claim 1, further comprising one or more of beta-carotene, alpha-tocopherol, caffeic acid, propyl gallate, and epigallocatechin gallate.
8. The ground beef-like food product of claim 1, further comprising one or more of a vegetable oil, an algal oil, sunflower oil, corn oil, soybean oil, palm fruit oil, palm kernel oil, safflower oil, flaxseed oil, rice bran oil, cottonseed oil, olive oil, canola oil, flaxseed oil, coconut oil, and mango oil.

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9. The ground beef-like food product of claim 1, further comprising coconut oil.

10. The ground beef-like food product of claim 1, further comprising lactic acid.

11. The ground beef-like food product of claim 1, comprising a textured vegetable protein.

12. The ground beef-like food product of claim 1, wherein the ground beef-like food product has a pink to red color before cooking to indicate a raw or uncooked state.

13. The ground beef-like food product of claim 1, wherein at least a portion of the ground beef-like food product, upon cooking, transitions in color from a pink to red color in a raw or uncooked state to a lighter pink to brown color in a partially cooked to fully cooked state.

14. The ground beef-like food product of claim 1, comprising about 5.6 to about 20 mM of the compound selected from glucose, ribose, fructose, lactose, xylose, arabinose, glucose-6-phosphate, maltose, and galactose, and mixtures of two or more thereof.

15. The ground beef-like food product of claim 1, comprising about 0.8 mM to about 10 mM cysteine.

16. The ground beef-like food product of claim 1, comprising about 0.1 mM to about 2 mM thiamine.

17. The ground beef-like food product of claim 1, wherein the at least two volatile compounds are selected from 2-methyl-furan, bis(2-methyl-3-furyl)disulfide, 2-pentyl-furan, 3,3'-dithiobis-2-methyl-furan, 2,5-dimethyl-pyrazine, 2-methyl-3-furanylthiol, dihydro-3-(2H)-thiophenone, 5-methyl-2-thiophenecarboxaldehyde, 3-methyl-2-thiophenecarboxaldehyde, 2-methyl-thiazole, dimethyl sulfide,

decanal, 5-ethyldihydro-2(3H)-furanone, dihydro-5-pentyl-2(3H)-furanone, 2-octanone, 3,5-octadien-2-one, p-Cresol, and hexanoic acid.

18. The ground beef-like food product of claim 1, wherein cooking comprises heating the ground beef-like food product at 150° C. for about 3 to about 5 minutes.

19. The ground beef-like food product of claim 1, further comprising one or more of acetic acid, lactic acid, glycolic acid, citric acid, succinic acid, tartaric acid, caprylic acid, capric acid, lauric acid, myristic acid, palmitic acid, palmitoleic acid, stearic acid, oleic acid, linoleic acid, alpha linolenic acid, gamma linolenic acid, arachidic acid, arachidonic acid, behenic acid, and erucic acid.

20. The ground beef-like food product of claim 1, wherein cooking the ground beef-like food product results in the production of at least five volatile compounds which have a beef-associated aroma.

21. The ground beef-like food product of claim 1, wherein cooking the ground beef-like food product results in the production of at least ten volatile compounds which have a beef-associated aroma.

22. The ground beef-like food product of claim 1, wherein cooking the ground beef-like food product results in the production of at least twenty volatile compounds which have a beef-associated aroma.

23. The ground beef-like food product of claim 1, wherein the at least two volatile compounds are 2-methyl-furan and bis(2-methyl-3-furyl)disulfide.

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